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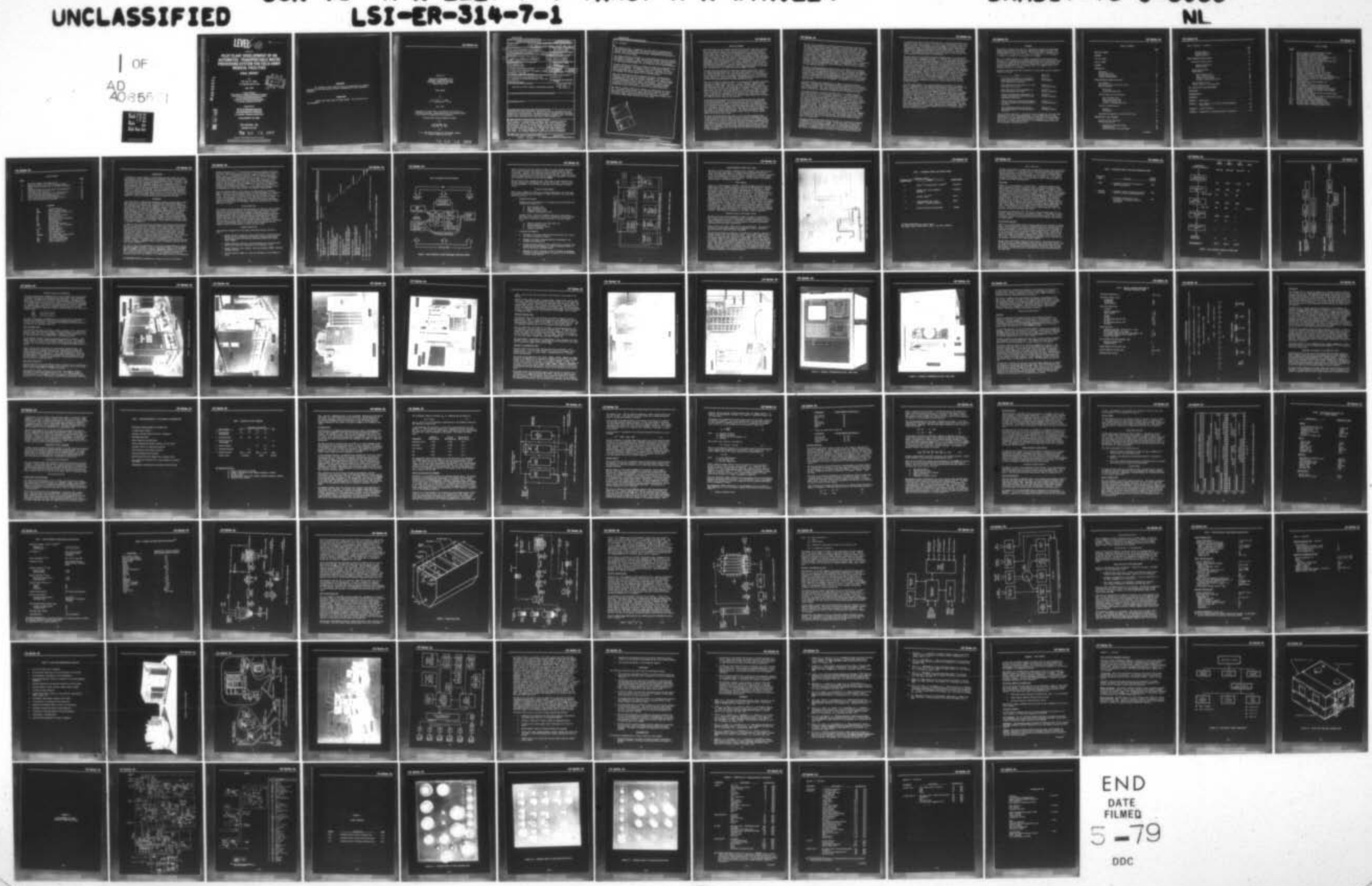

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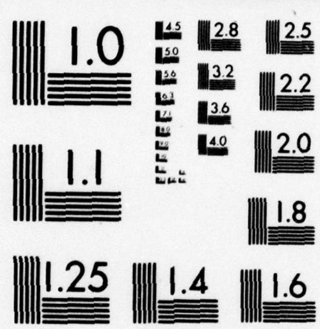

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PILOT PLANT DEVELOPMENT OF AN AUTOMATED, TRANSPORTABLE WATER PROCESSING SYSTEM FOR FIELD ARMY MEDICAL FACILITIES

FINAL REPORT

by

M.K. Lee, P.Y. Yang,

R.A. Wynveen and G.G. See

June, 1978

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Prepared Under Contract DAMD17-76-C-6063

by

LIFE SYSTEMS, INC.
Cleveland, OH 44122

for

U. S. Army Medical Research and Development Command
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A pilot plant of a transportable, integrated Water Processing System has been developed. The Water Processing System (WPS) treats nonsanitary wastewaters of the U.S. Army field hospitals either for nonpotable reuse or for surface discharge to the environment and purifies natural fresh and brackish waters for potable use. The WPS pilot plant consists of four units: (1) a Water Treatment Unit (WTU), (2) a Water Purification Unit (WPU), (3) a UV/Ozone Oxidation (O_3/UV) Unit and (4) an Automatic

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Instrumentation Unit. In addition, the pilot plant is equipped with a Data Acquisition System (DAS) which has also been developed under this program. This report describes the design, configuration and operation of both the WPS and the DAS.

The primary objective of the WTU is to remove suspended solids and turbidity from hospital wastewaters. When operated alone, the WTU treats the hospital wastewaters for surface discharge. It consists of three unit processes: (1) equalization/prescreening, (2) ultrafiltration and (3) hypochlorination.

The major function of the WPU is to remove most dissolved contaminants from process water streams. When operated alone, the WPU purifies natural waters for potable use. It consists of three unit processes: (1) natural water pretreatment by the use of depth filtration, carbon adsorption and ion exchange, (2) reverse osmosis and (3) hypochlorination.

When both the WTU and the WPU are operated in series, the WPS produces nonpotable reuse water from the hospital wastewaters. The O_3/UV unit is a supplementary unit either for the WTU or the WPU, while treating certain hospital wastewaters with high organic concentrations. The O_3/UV is used as a final purification step to destroy and eliminate residual organic contaminants in the process water. The Automatic Instrumentation Unit provides the control and monitor functions for the above three units.

The WPS has a nominal product water capacity of 3,500 gallons per 20-hour day. The product water recovery is at least 85% of inflow in the reuse water production and 90% in the potable water production. The overall contaminant removal efficiencies are 98.9% for total organic carbon, 99.5% for chemical oxygen demand and 98.5% for total solids.

EXECUTIVE SUMMARY

American soldiers do not question the quality of the water that comes from the tap. They drink and shower daily without any suspicion. Limited sources of natural fresh water, together with the possibility of ground water poisoning by the enemy, make the reclamation of wastewater for reuse extremely vital to the operation of the combat unit and the Army field hospital in water deficient areas. In response to this need, the U.S. Army Medical Research and Development Command has been developing a wastewater reuse system known as a water processing element. The interim objective is reuse of nonsanitary wastewaters for nonpotable hospital requirements. The ultimate objective is reuse for potable and nonpotable requirements. Under this program a full-scale pilot plant of a Water Processing System, equipped with a Data Acquisition System, was designed, built and delivered to the Army under Contract DAMD17-76-C-6063.

The Water Processing System pilot plant has a nominal product water capacity of 3,500 gallons per 20-hour day. The pilot plant consists of four units: (1) a Water Treatment Unit, (2) a Water Purification Unit, (3) an Ultraviolet/Ozone Oxidation Unit and (4) an Automatic Instrumentation Unit. The objective of this report is to describe the design, configuration and operation of both the Water Processing System and the Data Acquisition System.

There are two types of composite wastes in the nonsanitary wastewaters produced from the field Army medical facilities. One is a hospital composite waste consisting of shower (51%), operating room (26%), kitchen (12%), laboratory (8%) and X-ray waste (3%). The other type is a laundry composite waste consisting of 67% Type I (color-fast) and 33% Type II (woolens). In addition to the above wastes, the Water Processing System is to treat natural fresh or brackish water for potable use. The projected variations of the contaminant concentrations in the hospital wastewaters are 50-1,000 mg/l for total organic carbon and suspended solids, 300-6,000 mg/l for chemical oxygen demand, 500-4,200 mg/l for total solids and 5-900 JTU for turbidity.

In the Water Processing System there are two modes of operation: Reuse Mode and Potable/Discharge Mode. In the Reuse Mode the Water Processing System treats and purifies the nonsanitary hospital wastewaters for nonpotable reuse. In the Potable/Discharge Mode, it simultaneously treats those wastewaters for safe discharge to the environment while treating natural waters for potable use. The overall product recovery is at least 85% of inflow in the Reuse Mode and 90-95% in the Potable/Discharge Mode. The overall contaminant removal efficiencies are 98.9% for total organic carbon, 99.5% for chemical oxygen demand and 98.5% for total solids.

The Water Processing System pilot plant is one of the most advanced water treatment systems in which a number of state-of-the-art technologies and most recent advances in water processing have been integrated into a compact design. It has most of the features of the prototype Water Processing System which can be transported to a point of mission via conventional routes, such as standard cargo trucks, external helicopter loads, railroad, ship or cargo aircraft. In addition to treatments of the field Army hospital wastewaters and the natural waters, the pilot plant also can be used as a test bed for the general purpose of water treatment.

The unit processes employed in the Water Processing System include three of the most recent advances in water treatment: (1) ultraviolet/ozone oxidation, (2) reverse osmosis separation and (3) ultrafiltration separation. The ultraviolet/ozone oxidation is a chemical treatment process in which organic impurities are oxidized to carbon dioxide and water by ozone and ultraviolet light. It also can provide a 100% killing of bacteria, viruses or any other known microorganisms, a complete destruction of color and odor, and an improvement of taste. Both the reverse osmosis and the ultrafiltration separation techniques are physical treatment processes in which a semipermeable membrane separates dissolved or suspended contaminants from permeable water. In addition, the Water Processing System employs a number of conventional water treament processes such as ion exchange, carbon adsorption, depth filtration, equalization and hypochlorination.

The Water Processing System was sized to treat 4,118 gal/day of the hospital wastewaters and 3,900 gal/day of the natural waters. The unique requirements for the Water Processing System design are: (1) limited allowance on dimensions, weight and power consumption for transportation and field application; (2) automatic instrumentation and minimum maintenance for unskilled operators; and (3) pilot plant capabilities and semiautomatic instrumentation for performance evaluation and scientific data development. The system is to be operated 20 hours per day.

For ease of handling and transportation, a number of treatment processes employed in the Water Processing System have been integrated into three units: (1) a Water Treatment Unit, (2) a Water Purification Unit and (3) an Ultraviolet/Ozone Oxidation Unit. The control and monitor instrumentation for the three units is provided by a separately packaged Automatic Instrumentation Unit.

The primary objective of the Water Treatment Unit is to remove suspended solids and turbidity from the hospital wastewaters. In the Reuse Mode, the Water Treatment Unit is a pretreatment unit for the Water Purification Unit, but in the Potable/Discharge Mode it operates as an independent unit to treat the hospital wastewaters for discharge to the environment. The overall contaminant removal efficiencies of the Water Treatment Unit are approximately 99% for suspended solids and turbidity. The Water Treatment Unit consists of three unit processes: (1) equalization/prescreening, (2) ultrafiltration and (3) hypochlorination. The equalization/prescreening process separates gross suspended solids from the wastewater influent and equalizes time-varying hydraulic loading and concentration variations to result in a more uniform feed to the ultrafiltration process. In the ultrafiltration process, suspended solids and some dissolved solutes with a molecular weight greater than 15,000 are separated from the process water stream. The hypochlorination process is used to maintain 2 mg/l of free residual chlorine in the surface discharge water for disinfection.

The major function of the Water Purification Unit is to remove most dissolved contaminants from process water streams. In the Reuse Mode, the Water Purification Unit is the secondary treatment unit for the hospital wastewaters pretreated in the Water Treatment Unit, but in the Potable/Discharge Mode it operates as an independent unit to purify the natural waters for potable use. The overall contaminant removal efficiencies of the Water Purification Unit

are approximately 98% for total solids and salts. The Water Purification Unit consists of three unit processes: (1) natural water pretreatment by the use of depth filtration, carbon adsorption and ion exchange, (2) reverse osmosis and (3) hypochlorination. The natural water pretreatment process separates suspended solids, organisms and hardness from the natural waters. The reverse osmosis process separates dissolved solids and salts from the process water streams. The hypochlorination process maintains 5 mg/l of free residual chlorine in potable and reuse waters for disinfection.

The main objective of the Ultraviolet/Ozone Oxidation Unit is to destroy and eliminate organic contaminants in water. It consists of an ozone generator, a precontactor and a six-stage ozone contactor. In the Reuse Mode the Ultraviolet/Ozone Oxidation Unit is the third treatment unit for the hospital wastewaters pretreated in both the Water Treatment Unit and the Water Purification Unit. In the Potable/Discharge Mode, it serves as a supplementary unit of the Water Treatment Unit to produce a safe discharge water from certain hospital wastewaters with high organic concentrations or potential pathogens. The contaminant removal efficiencies are greater than 84% for total organic carbon and 91% for chemical oxygen demand. Results of the ultraviolet/ozone oxidation kinetic study indicated that the reduction rate of total organic carbon is first-order with respect to the total organic carbon concentration. It was also found that the reaction rate has a 1.5th-order dependence on the ozone partial pressure and the air superficial velocity. Based on the results a reactor design equation was developed to scale-up the ozone contactor for the full-scale pilot plant.

The pilot plant employs one of the most advanced instrumentation concepts which is highlighted by a minicomputer-based automatic control and monitor and by the capability of the fault detection/isolation and performance trend analysis. For the safety of the system itself and its operator, the Water Processing System is protected from damages which may result from: (1) illegal operation by unauthorized personnel, (2) any mistakes (unauthorized commands) of unskilled operators and (3) component failures or any abnormal operating conditions. The start-up and operation of the system is accomplished simply by pressing a single button after a valid password is entered through a keyboard panel. The keyboard panel and a cathode-ray tube screen on the instrumentation unit serve as a communication tool between the system and the operator. For pilot plant testing a number of flexibilities such as semiautomatic instrumentation and manual overrides for major components were incorporated. The pilot plant can be operated at a remote terminal with all of its control, monitor and data acquisition benefits.

FOREWORD

This study was conducted for the U. S. Army Medical Research and Development Command, Fort Detrick, Frederick, MD, under Contract DAMD17-76-C-6063. The Program Manager was Dr. R. A. Wynveen. Technical effort was completed by Dr. M. K. Lee, Dr. P. Y Yang, Dr. J. Y. Yeh, J. D. Powell, Jr., J. O. Jessup, D. C. Walter, K. E. Brown, G. G. See and Dr. W. J. Knebel.

Maj. W. P. Lambert and Mr. W. J. Cooper, Environmental Protection Research Division, U. S. Army Medical Bioengineering Research and Development Laboratory, Fort Detrick, Frederick, MD, were the Technical Monitors of this program. We also wish to acknowledge the technical contributions, assistance and program guidance offered by Lt. Col. L. H. Reuter, Maj. W. P. Lambert, Capt. J. J. McCarthy and Capt. B. W. Peterman.

Results of this study have been published in a final report and five technical reports as follows:

Title	Report No.
Pilot Plant Development of an Automated, Transportable Water Processing System for Field Army Medical Facilities	ER-314-7-1 (Final Report)
Water Treatment Unit Development for Field Army Medical Facilities	ER-314-7-2 (Technical Report)
Water Purification Unit Development for Field Army Medical Facilities	ER-314-7-3 (Technical Report)
Advanced Instrumentation Development for a Water Processing Pilot Plant for Field Army Medical Facilities	ER-314-7-4 (Technical Report)
UV/Ozone Oxidation Technology Development for Water Treatment for Field Army Medical Facilities	ER-314-7-5 (Technical Report)
Data Acquisition, Monitor and Control System Development for Field Army Medical Facilities	ER-314-7-6 (Technical Report)

The first report, ER-314-7-1, outlines the overall program for the pilot plant development of a Water Processing System. The succeeding reports present further details on the subsystem developments of the Water Processing System pilot plant. The pilot plant consists of four subsystems: (1) a Water Treatment Unit, (2) a Water Purification Unit, (3) a UV/Ozone Oxidation Unit and (4) an Automatic Instrumentation Unit.

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ACRONYMS

CA	Carbon Adsorption
COD	Chemical Oxygen Demand
DAMCS	Data Acquisition, Monitor and Control System
DAS	Data Acquisition System
DF	Depth Filtration
EP	Equalization and Prescreening
HC	Hypochlorination
IE	Ion Exchange
JTU	Jackson Turbidity Unit
MUST	Medical Unit, Self-Contained, Transportable
O_3/UV	UV/Ozone Oxidation
RO	Reverse Osmosis
TOC	Total Organic Carbon
UF	Ultrafiltration
USAMRDC	U.S. Army Medical Research and Development Command
WPS	Water Processing System
WPU	Water Purification Unit
WTU	Water Treatment Unit

INTRODUCTION

A sufficient, reliable supply of safe drinking water has played one of the most important roles on fighting in water-deficient areas such as Africa and Indochina during World War II, Vietnam and Middle East Asia. Recently, a safe water supply has been recognized as important to the success of the U.S. Army operation as are other expendable supplies such as ammunition and food. Unlike ammunition and food, safe drinking water can be produced on-site near the battle field and wastewaters generated in the Army installations can be recycled for reuse after treatment. Such water management may significantly reduce or ultimately eliminate the logistical burden of the Army operation associated with hauling a huge amount of water to each new field installation. In addition, American soldiers' health and lives are not permitted to be in danger as a result of drinking natural waters poisoned by the enemy.

Background

Since 1962 the U.S. Army has been developing a mission-oriented medical treatment system known as Medical Unit, Self-Contained, Transportable (MUST).(1) The system has to be designed and equipped to facilitate rapid establishment and disestablishment and to permit immediate response by medical support units to any tactical, environmental or geographical change. Associated with the MUST hospital is the Water and Waste Management Subsystem which is required to treat and dispose of all toxic and contaminated waste materials generated within the functional areas of the hospital. The subsystem is composed of three principal elements: a utility room element, a water processing element and a mobile incinerator. The WPS must be capable of producing potable water from natural water sources and treating hospital wastewaters either for reuse or for safe discharge to the environment. Further details of the MUST concept is presented in Appendix 1.

In 1968 the first prototype WPS was developed by the AiResearch Manufacturing Division of the Garrett Corp., Phoenix, Arizona, under contract to the Army. The prototype WPS consisted of two units: (1) a WTU with waste collection, coagulation/ floatation, pressure filtration and chlorination and (2) a WPU with cartridge filters, reverse osmosis, activated carbon, marble chips and chlorination. Extensive tests of the prototype unit performed by the Army revealed deficiencies in various processes such as waste collection, floatation, filtration, chlorination, activated carbon and pH adjustment. The water treatment unit failed to produce a water of acceptable turbidity and free chlorine residual. The product water of the WPU did not meet the water quality criteria for ammonia, nitrogen content, organic contaminant concentrations and free chlorine residual.(1)

In order to correct the deficiencies in the first prototype WPS and to improve the overall system performance, the U.S. Army Medical Research and Development Command (USAMRDC) initiated an extensive development program for an advanced WPS. During the period 1971 to 1976 the USAMRDC sponsored various projects on new process and system developments such as: (a) feasibility studies of various processes for the treatment of the MUST hospital waste at the AiResearch

(1) References cited in parentheses are listed at the end of this report.

Manufacturing Division,[2] (b) bench scale evaluation of membrane separation processes, carbon adsorption and ozonation at the Walden Research Division of Abcor, Inc.,[3] (c) development of an ozone contactor system and a reverse osmosis separation system at Life Systems, Inc.[4] and (d) the development of an advanced automatic instrumentation at Life Systems, Inc.[5] In parallel, other related and fundamental studies on reverse osmosis membranes, ozone oxidation and ultrasound effect have been carried out at the University of Illinois, the University of Arizona and the U.S. Army Medical Bioengineering Research and Development Laboratory.[6-10] As a result of these efforts candidate unit processes were identified and the preliminary engineering data was developed for a pilot plant design of an advanced, automated WPS.

Under the present program a pilot plant of an advanced WPS was developed. Figure 1 shows the overall program schedule for the development of an advanced WPS for field Army medical facilities along with the projected future milestones. The pilot plant development was an important intermediate step of the overall WPS development activity. Following the redefinition of the WPS research and development requirements, it precedes the prototype development. Figure 2 illustrates how the development transition from bench scale to prototype effort occurred.

Program Objectives

The objective of this program was the development of a WPS pilot plant equipped with a data acquisition, monitor and control system, which would be used to develop the new and improved water treatment technology necessary to build advanced prototype water processing systems for field Army medical facilities. The WPS should be capable of processing natural fresh/brackish and medical complex wastewaters for the production of potable and reuse water. The data acquisition, monitor and control system should acquire experimental data on the pilot plant, various other water treatment processes and parallel laboratory research and development efforts, and should control and monitor the test support accessories (TSA) needed to operate the pilot plant.

Program Organization

The program was organized into four major tasks whose specific objectives were:

1. Design, fabricate, check out, deliver and start up a fully-functional WPS pilot plant, excluding the ultraviolet, light-activated ozone (O_3/UV) unit process and the Data Acquisition, Monitor and Control System (DAMCS).

2. Design, fabricate, check out, deliver and start up a fully-functional O_3/UV unit process for integration with the WPS pilot plant.

3. Design, fabricate, test, install, start up and debug a DAMCS, including computer software.

4. Provide technical support to insure the operability of the WPS pilot plant.

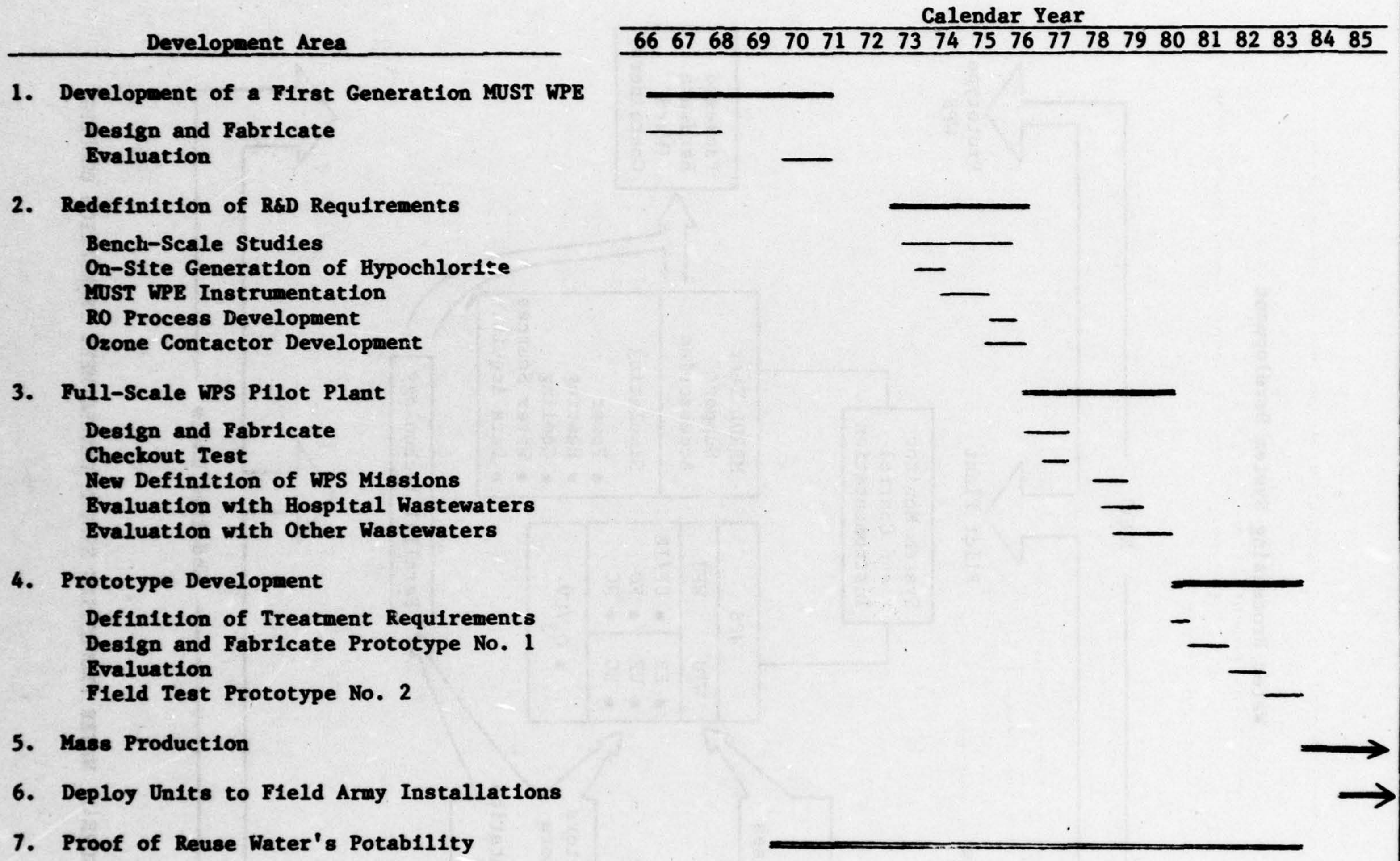


FIGURE 1 WATER PROCESSING SYSTEM DEVELOPMENT SCHEDULE

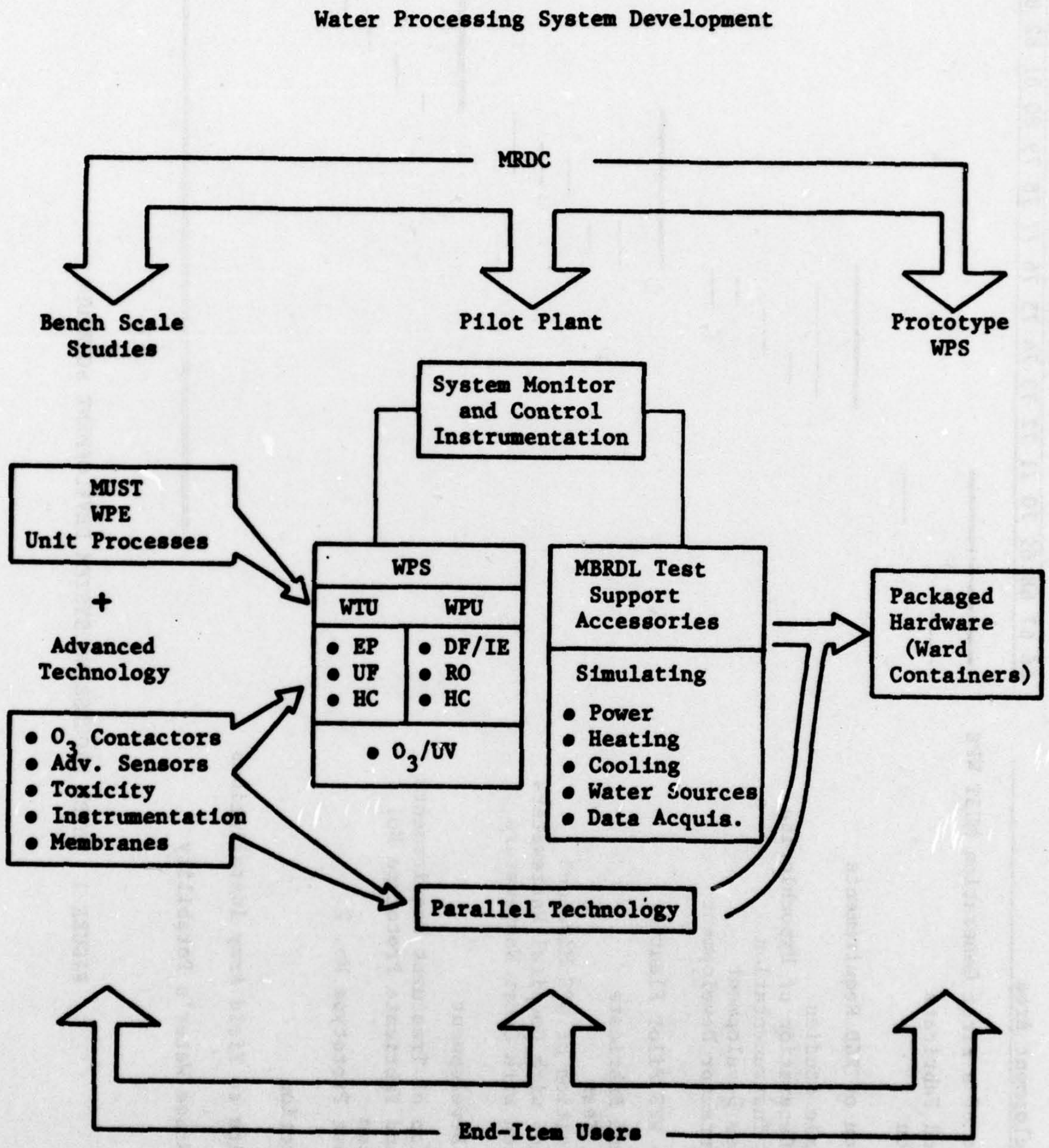


FIGURE 2 WATER PROCESSING SYSTEM DEVELOPMENT TRANSITION CONCEPT

Figure 3 shows the interface between the WPS pilot plant and the TSA needed for its characterization and operation within a simulated medical complex environment. The WPS, a Data Acquisition System (DAS) and the TSA control/ monitor instrumentation were developed under this program. Other TSA such as utility element simulations, water sources simulations, expendables and product water handling facilities were provided by USAMRDC.

The objectives of the program were met. This report briefly describes the design, configuration and operation of the WPS and the DAS. Further details on the developments of the WPS and the DAS have been published in separate reports.

Program Accomplishments

Under Contract DAMD17-76-C-6063 the following accomplishments have been made in hardware and technology development of a WPS to be used in the field Army medical facilities:

1. Hardware Developments

   Designed, built and checked out an automated transportable WPS pilot plant which consisted of a:

   - Water Treatment Unit
   - Water Purification Unit
   - UV/Ozone Oxidation Unit
   - Automatic Instrumentation Unit

   Designed, built, tested and debugged a DAS which could provide a data acquisition function for up to 16 satellites including the WPS. Any of the 16 satellites could be operated at from four command posts:

   - Operator station at the Pilot Plant Site
   - Project Engineer Office
   - Biological Treatment Trailer
   - Chemistry Laboratory

2. Technology Developments

   - **Developed a full-scale system from the bench-scale test results of previous treatability studies**

   - **Designed first fully integrated WPS with semiautomatic and automatic instrumentations.**

   - **Provided the pilot plant with the capability for scientific and engineering data developments to allow an optimized design of the next generation prototype system.**

   - **Advanced the O_3/UV technology for water treatment by expanding knowledge on reaction mechanisms and kinetics and by developing a reactor design equation.**

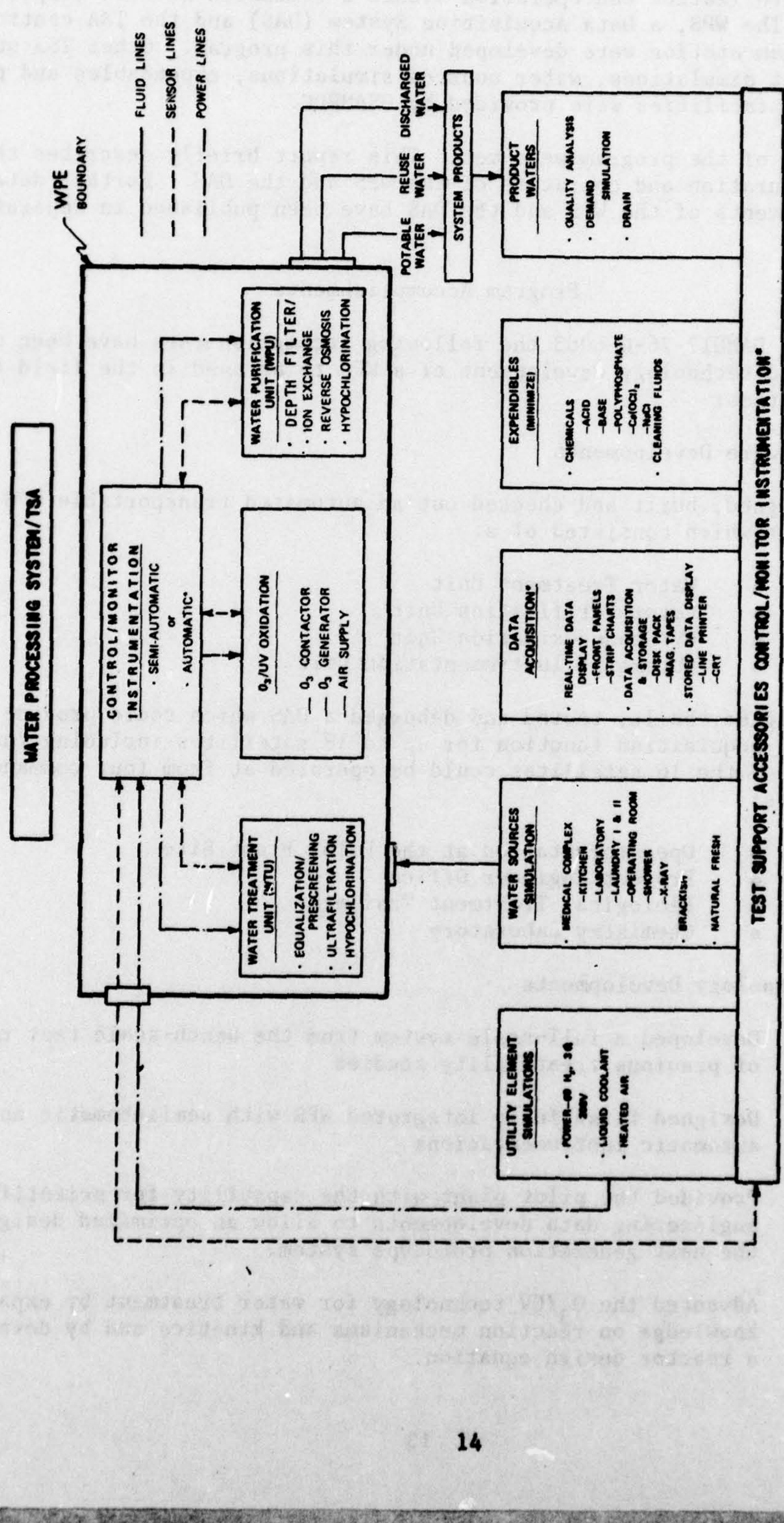


FIGURE 3 WPS PILOT PLANT INTERFACE BLOCK DIAGRAM

WATER PROCESSING SYSTEM PILOT PLANT

The WPS is a fully-automated, integrated water treatment system which fulfills three functional requirements: (1) potable water production from natural waters; (2) nonpotable reuse water production from hospital wastewaters generated in the field Army medical facilities and (3) treatment of the hospital wastewaters for safe discharge to the environment. The WPS employs a minicomputer-based automatic instrumentation package.

Flow Schematic

Figure 4 is a flow diagram of the WPS. Hospital wastewater collected in the equalization tank is pumped through ultrafiltration (UF) membranes. Depending on the mode of operation, the permeate stream of the UF membranes is further purified for reuse by reverse osmosis (RO) membranes, or discharged to the environment either through a hypochlorination (HC) unit (calcium hypochlorite mixers) or through an ozone contactor and the HC unit. The permeate stream of the RO membranes flows to the reuse water storage tank either through the other HC unit (lower one) or through the ozone contactor and the HC unit, depending on the organic content in the wastewater. The ozone contactor is an oxidation reactor in which the organic impurities in the wastewater are oxidized to carbon dioxide and water by ozone and ultraviolet light. Ozone is produced from oxygen in air. Potable water is produced by purifying natural fresh and brackish waters. The natural water purification follows a sequence of depth filtration (DF), carbon adsorption (CA), ion exchange (IE), RO and HC processes. A detailed description and operation of the WPS are presented in the following sections. The detailed flow schematic of the WPS is shown in Appendix 2.

Wastewater Sources and Product Waters

The WPS pilot plant has been designed to treat two types of contaminated water: natural waters and nonsanitary hospital wastewaters generated in the field Army medical facilities. In addition, the pilot plant may be used to conduct treatability studies for various types of wastewaters generated by other Army field and fixed installations.

Natural waters are further classified as fresh and brackish. The quality of the natural waters highly depends on the geographic location, industrial pollution and the activities of man and animal.

The nonsanitary hospital wastewaters are divided into a hospital composite, a laundry composite and seven individual wastes. The hospital composite waste consists of operating room, laboratory, X-ray, shower, and kitchen wastes. The laundry composite waste consists of laundry Type I (color fast) and Type II (woolens). Based on the wastewater characteristics, and for convenience in the process control, the hospital wastewaters are classifed into four groups. Table 1 shows the classification of wastewater sources, along with the product waters. The product waters are classifed into three groups according to the purpose of water treatment: (1) discharge water, (2) nonpotable reuse water and (3) potable water. Each classification of the wastewater sources requires a different combination of treatment processes.

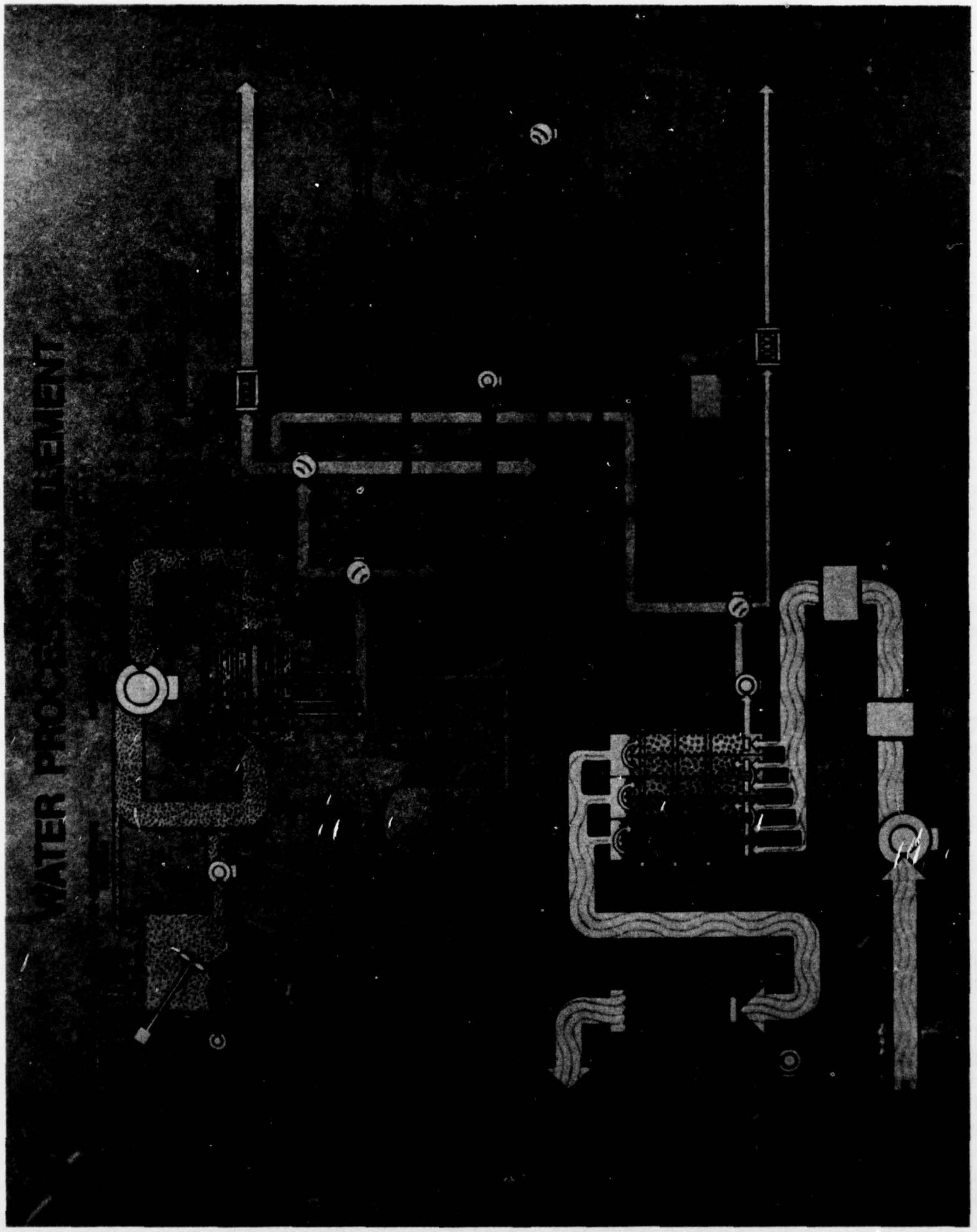


FIGURE 4 FLOW DIAGRAM OF WATER PROCESSING SYSTEM PILOT PLANT

TABLE 1 WASTEWATER SOURCES AND PRODUCT WATERS

Wastewater Source Classification	Source	Product Water
A	Shower,[a] Operating Room, Laundry[b]	Discharge
B	Kitchen, Lab, X-ray, Hospital Composite	Discharge
C	Kitchen, Shower[a]	Reuse
D	Operating Room, Lab, X-ray, Laundry,[a] Hospital Composite	Reuse
E	Natural Fresh and Brackish Water	Potable

(a) Shower waste includes lavatory water
(b) Laundry wastes include Type I, Type II and their composite

Mode of Operation

The WPS can be operated in either one of two operational modes: Reuse and Potable/ Discharge (Table 2). In the Reuse Mode the WPS treats and purifies nonsanitary hospital wastewaters for nonpotable reuse. In the Potable/ Discharge Mode it simultaneously treats those same wastewaters for discharge to the environment while treating natural fresh or brackish water for potable use. The overall recovery of the product water is at least 85% of inflow in the Reuse Mode and 90-95% in the Potable/Discharge Mode.

Reuse Mode

Figure 5 is a block diagram of the Reuse Mode. Nonsanitary hospital wastewaters (wastewater Sources C and D) are fed to the equalization/prescreening (EP) process in which gross suspended solids are removed. In addition, the EP process equalizes time-varying hydraulic loading and concentration variations to result in a more uniform feed to the UF process. In the UF process, the suspended and dissolved solutes with a molecular weight greater than 15,000 are separated to minimize the fouling and maintenance of the RO membranes. The function of the RO process is to remove most of the dissolved organics with a molecular weight of 150 to 15,000. The residual low molecular weight organic solutes remaining in the RO permeate of the Source D wastewater are finally oxidized in the O_3/UV process to meet the water quality specifications for nonpotable use: 5 mg/l total organic carbon (TOC) and 10 mg/l chemical oxygen demand (COD), or less. The O_3/UV process is not needed for the treatment of the wastewater Source C. The hypochlorination (HC) process is used to maintain 5 mg/l free residual chlorine in the product reuse water.

The typical distribution of TOC, COD and total solids concentrations for the hospital composite wastewater is also shown in Figure 5. The numbers in parentheses are the typical rejection percents for each unit process. The overall contaminant removal rates projected are 98.9% for TOC, 99.5% for COD and 98.5% for total solids.

Potable/Discharge Mode

Figure 6 is a block diagram of unit processes employed in the Potable/ Discharge Mode. The WPS performs two separate, independent functions simultaneously: (1) potable water production from natural fresh or brackish water and (2) hospital wastewater treatment to protect the environment from toxic waste discharge. A total of nine processes are included in both treatment trains. The RO process is the main stage of the potable water treatment, while the UF process is the heart of the hospital wastewater treatment for discharge. Each train has its own HC unit. The O_3/UV process in the surface discharge train is used only for the wastewater source B with a high organic loading.

Natural water pretreatment consists of DF, CA and IE. The primary function of the DF process is to remove suspended solids from the natural water stream. The CA column is employed to remove natural organics (humic acids) which may foul the IE resin. The hardness of the influent water is reduced in the IE column. The functions of other processes are basically the same as those described in the Reuse Mode.

TABLE 2 OPERATIONAL MODES OF THE WATER PROCESSING SYSTEM

Operational Mode	Function	Product Recovery
1. Reuse	• Treatment and Recycle of Nonsanitary Hospital Wastewaters	85%
2. Potable/ Discharge	• Treatment of Natural Fresh and Brackish Waters for Potable and Nonpotable Use	90%
	• Treatment and Discharge to the Environment of Nonsanitary Hospital Wastewaters	95%

		TOC (mg/1)	COD (mg/1)	TS (mg/1)	Ref.
Nonsanitary Hospital Wastewaters		50-1,000	300-6,000	500-4,200	(3)
↓					
Equalization/ Prescreening (EP)					
↓		463	1,875	1,240*	*(3)
Ultrafiltration (UF)		(73%)	(76%)	(26%)	
↓	MW ≤ 15,000	125	450	918	
Reverse Osmosis (RO)		(76%)	(76%)	(98%)	
↓	MW ≤ 150	30*	108*	18	*(16)(17)
UV-Ozone Oxidation (O_3/UV)		(≥84%)	(≥91%)	--	
↓		≤5	≤10	--	
Hypochlorination (HC)		--	--	--	
↓					
Nonpotable Reuse Water		≤5	≤10	--	
<u>Total Removal %</u>		(≥98.9)	(≥99.5)	(≥98.5)	

FIGURE 3 UNIT PROCESSES INVOLVED IN REUSE MODE

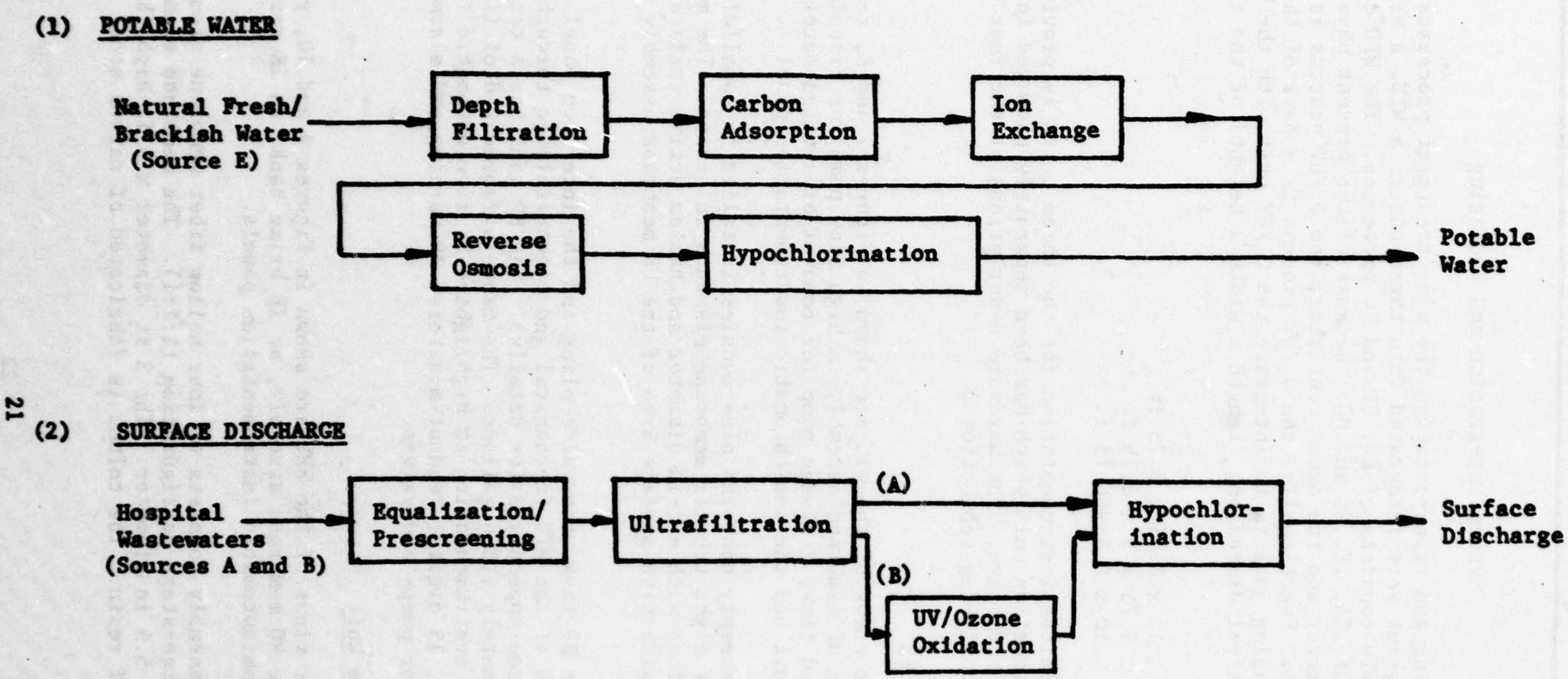


FIGURE 6 UNIT PROCESSES INVOLVED IN POTABLE/DISCHARGE MODE

System Integration and Packaging

For ease of handling and transportation the nine treatment processes employed in the WPS pilot plant were integrated into three units: a WTU, a WPU and a O_3/UV Unit. The WTU consists of EP, UF and HC processes. The WPU contains the processes of DF, CA, IE, RO and HC. Because of the present physical size of the ozone generator and the ozone contactor, the O_3/UV process is packaged as a separate unit. Functionally, the O_3/UV process is a part of the WTU and the ultimate packaging goal is to integrate the O_3/UV unit with the WTU package. The physical dimensions (length x width x height) of the three units are as follows:

WTU:	12 x 8.75 x 6.75 ft
WPU:	9.75 x 5 x 6.75 ft
O_3/UV:	10 x 8.5 x 6.75 ft

The control and monitor instrumentation for the three units is provided by an automatic instrumentation unit which has been separately packaged into a 21 x 21 x 28.5 in enclosure. The hardware descriptions of the four units are presented in the following subsections.

Water Treatment Unit

The front and rear views of the WTU are shown in Figures 7 and 8, respectively. Figure 7 shows the UF membrane assembly, a high flow pump for circulation of UF recycle and feed flow, a sludge pump for removal of settled material in the EP tank, the HC unit and the semiautomatic instrumentation panel.

The UF membrane assembly contains nine modules installed in parallel. Each module consists of eight tubular membrane elements in series. The membrane element is 10 ft long with a 1-in diameter and has an active surface area of 2.2 ft^2. The total active surface area of the UF membrane assembly amounts to 158 ft^2.

Figure 8 shows the EP tank, the valve plane and the interface panel. All inputs and outputs of the WTU (mechanical and electrical) go through the interface panel (see Appendix 3 for details). The EP tank has a total wet volume of approximately 1,300 gallons. The tank is fabricated of fiberglass. The semiautomatic instrumentation is highlighted by five automatic fail-safe shutdown controls, 13 digital readout monitors, 10 warning and alarm lights, and 26 controls for pumps and valves.

Water Purification Unit

The front and rear views of the WPU are shown in Figures 9 and 10, respectively. Figure 9 shows the RO membrane assembly, an IE brine tank, an IE resin column, filters and the semiautomatic instrumentation panels.

The RO membrane assembly consists of four hollow fiber membrane elements installed in a three-stage configuration (2:1:1). The membrane element is 47 in long with a 5.5 in diameter. The 3 ft diameter x 5 ft high IE column contains 21 ft^3 of resin. The column is fabricated of carbon steel lined with

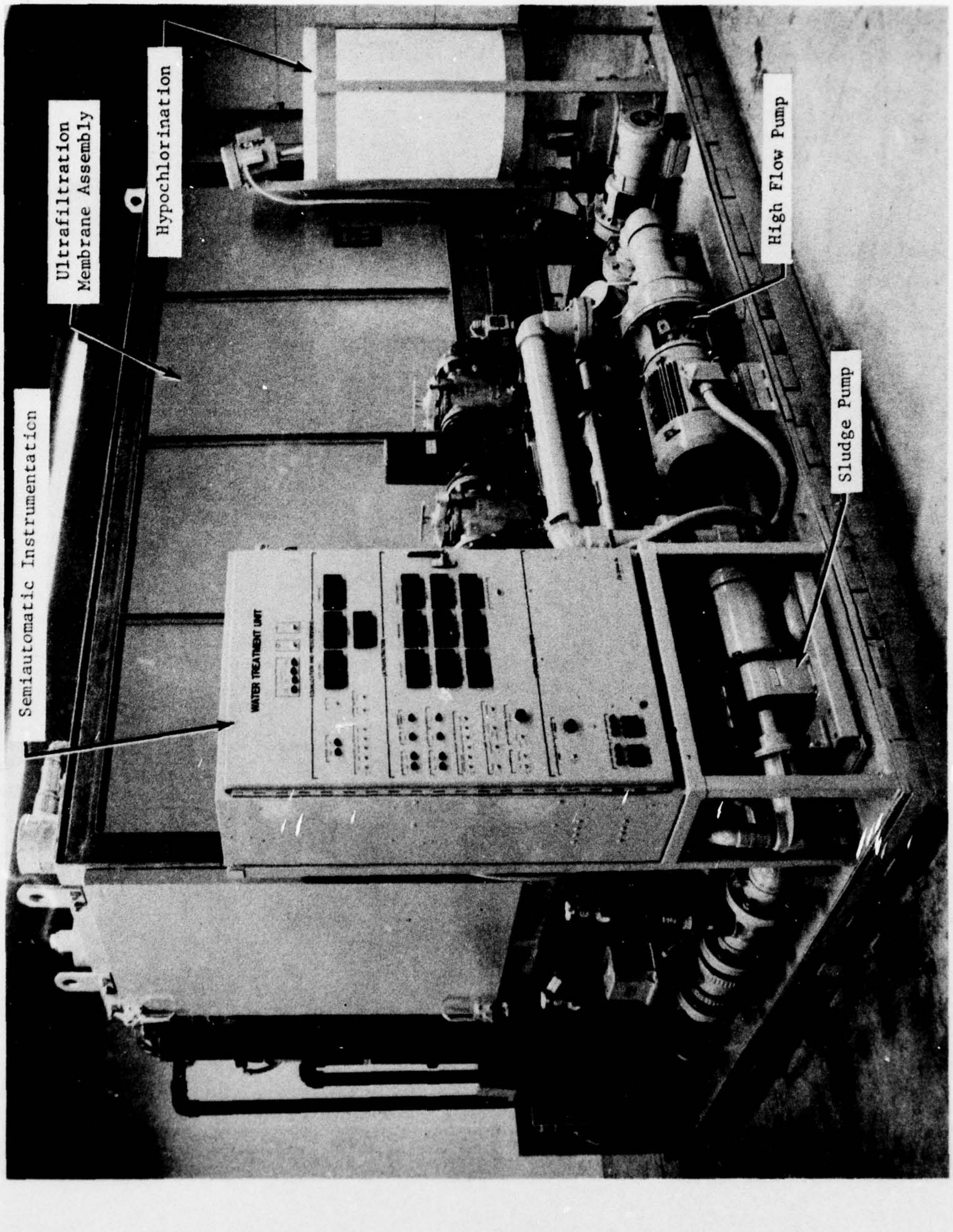


FIGURE 7 WATER TREATMENT UNIT, FRONT VIEW

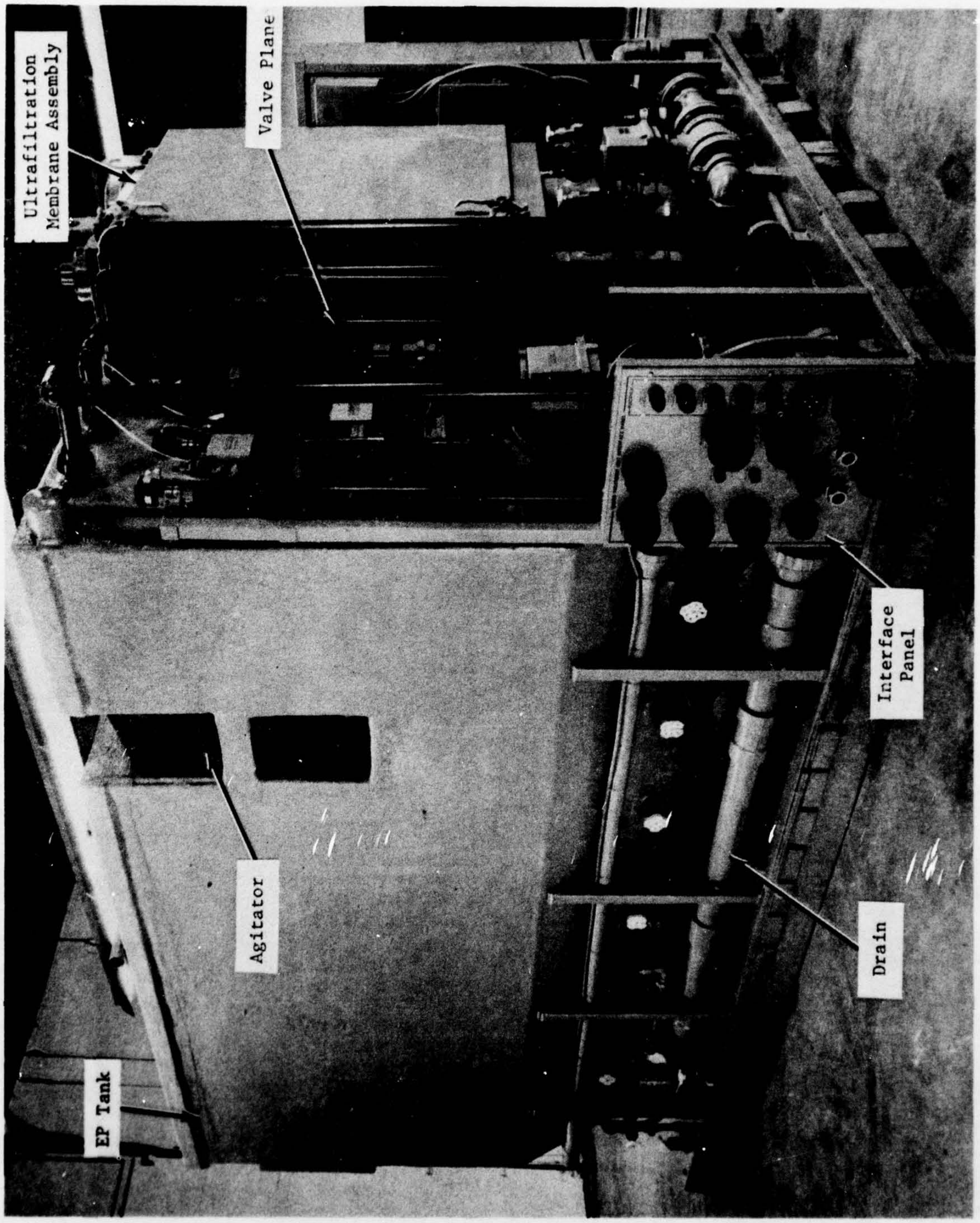


FIGURE 8 WATER TREATMENT UNIT, REAR VIEW

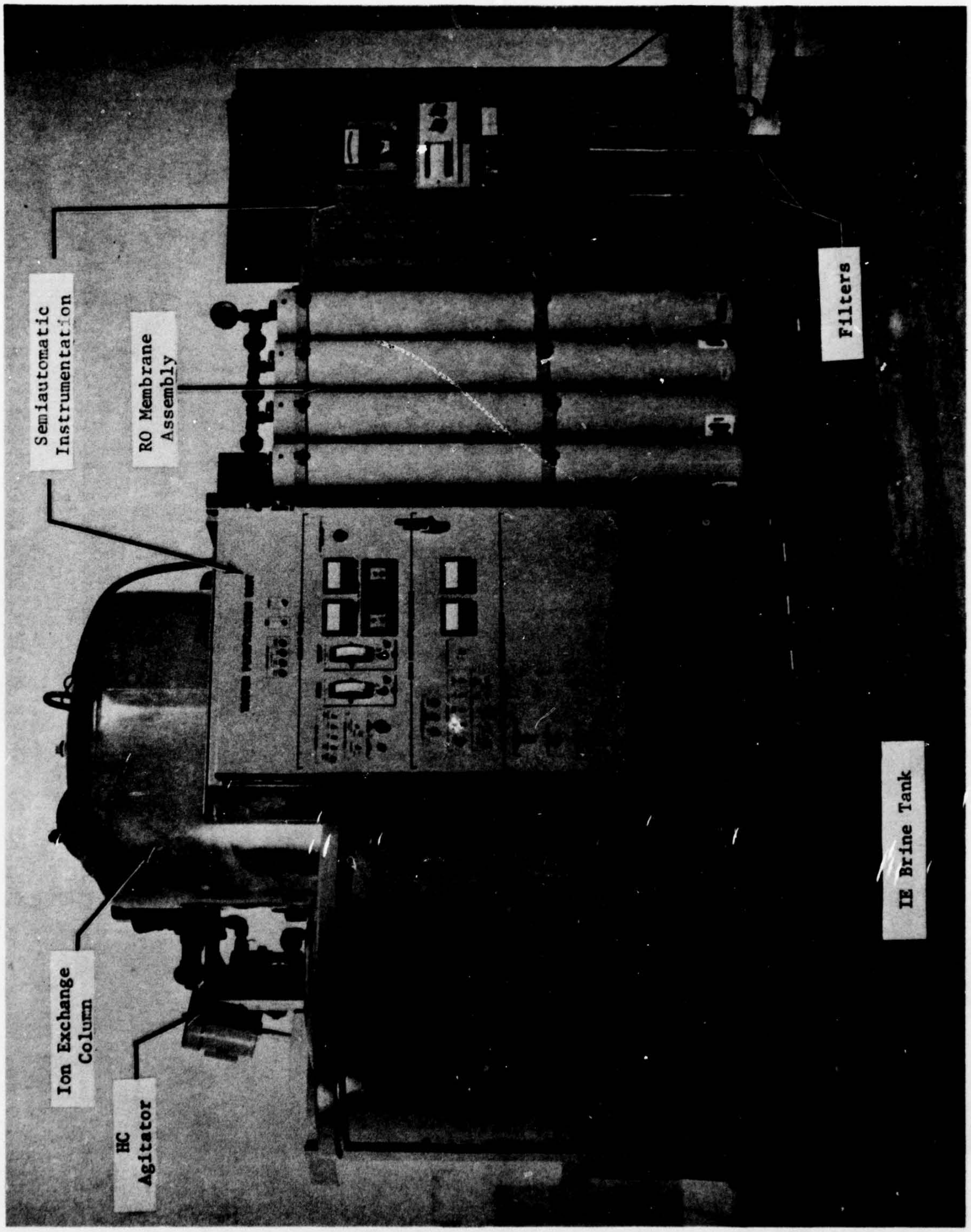


FIGURE 9 WATER PURIFICATION UNIT, FRONT VIEW

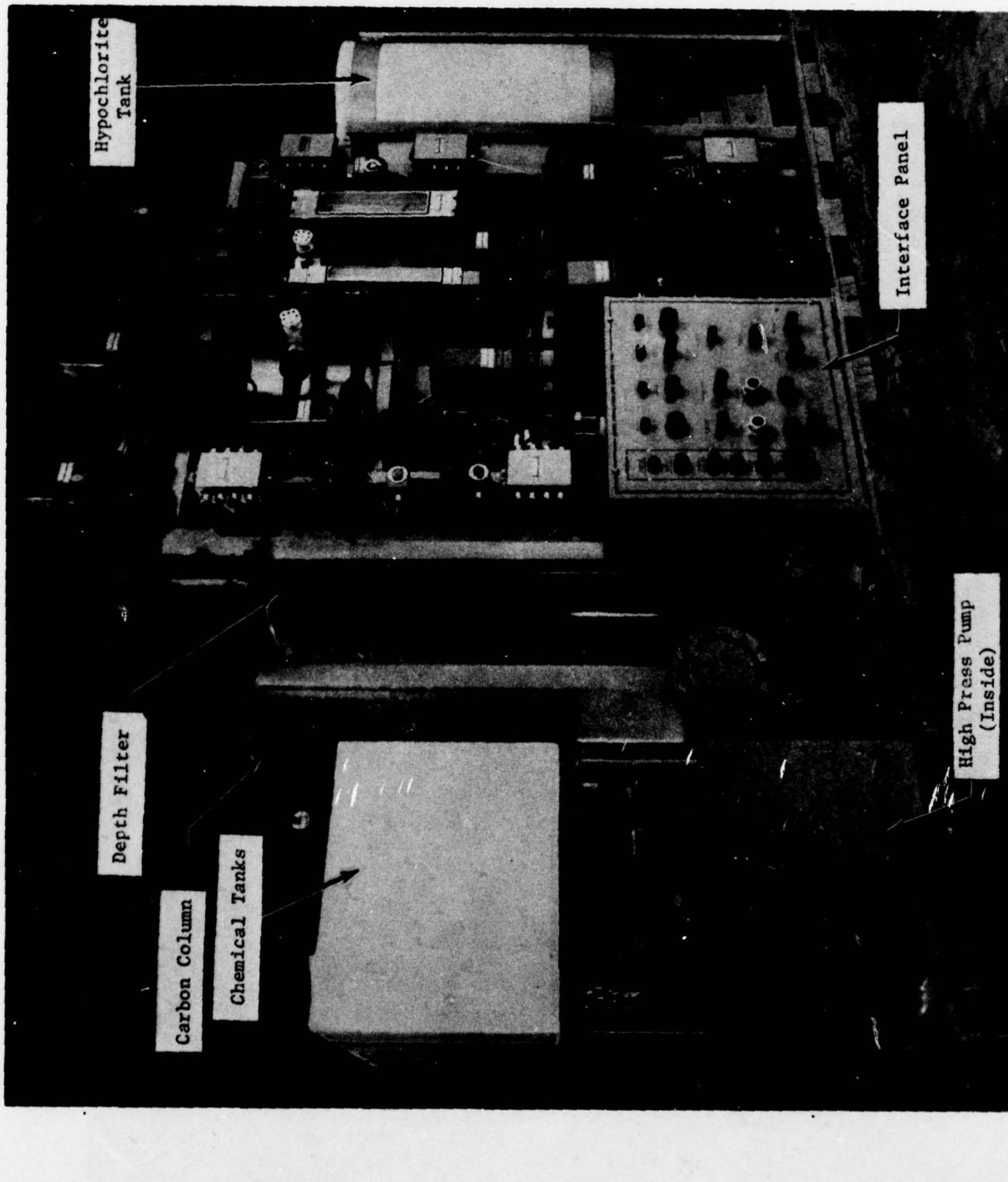


FIGURE 10 WATER PURIFICATION UNIT, REAR VIEW

epoxy. The IE brine tank is fabricated of PVC and has a dry volume of 210 gallons.

Figure 10 shows chemical tanks, a carbon column, a depth filter and the interface panel. Both the carbon column and the depth filter are 4.5 ft high with a 1 ft diameter and are constructed of carbon steel with an epoxy lining. The carbon column contains 2 ft^3 of granular activated carbon. The depth filter consists of three beds: anthracite (21 in bed height); sand (10 in) and gravel (6 in). The semiautomatic instrumentation has seven automatic fail-safe shutdown controls, 12 readout monitors, ten warning and alarm lights, and 29 controls for pumps and valves.

UV/Ozone Oxidation Unit

The front and side view of the O_3/UV unit are shown in Figures 11 and 12, respectively. Figure 11 shows an ozone generator, the semiautomatic instrumentation panel, an air compressor and pumps for feed and product waters. The ozone generator produces 25 lb ozone per day (at 1% by weight) from air. The air compressor feeds 24 scfm of air at 60 psig to the ozone generator.

Figure 12 shows the ozone contactor, UV lamps, an ultrasound generator, the air compressor, the valve plane and the interface panel. The ozone contactor consists of three reactor modules with an overall dimension of 40 x 61 x 79 inches. Each module has two stages and 20 UV lamps. The total wet volume of the ozone contactor is 544 gallons. The ultrasound generator is incorporated into the first stage to enhance the ozone mass transfer rate.

The semiautomatic instrumentation is highlighted by seven automatic fail-safe shutdown controls, eight digital readout monitors, 10 warning and alarm lights, and 26 controls for pumps, valves and UV lamps.

Automatic Instrumentation Unit

Figures 13 and 14 show the front and rear panels of the Automatic Instrumentation Unit. The front panel consists of a system status summary with a message display screen, a control panel, a keyboard panel and a recessed manual override panel.

The system status summary has four lights: NORMAL, CAUTION, WARNING and ALARM. Except for the NORMAL status, messages are displayed on cathode-ray tube (CRT) display screen indicating the cause of the CAUTION, WARNING or ALARM. The control panel provides the operator with pushbutton switches and lamp indicators for ease of selecting a system command (POWER, NORMAL, STANDBY and SHUTDOWN), wastewater sources and product waters, and auxiliary maintenance controls such as UF membrane cleaning, RO membrane cleaning, IE bed regeneration and system drain.

The keyboard panel and the message display screen provide the operator with a convenient way of communicating with the system. Through the keyboard panel the operator can examine and modify control or monitor setpoints of various process parameters. On-line display of parametric data also can be requested. The requested information as well as operator error messages and other messages

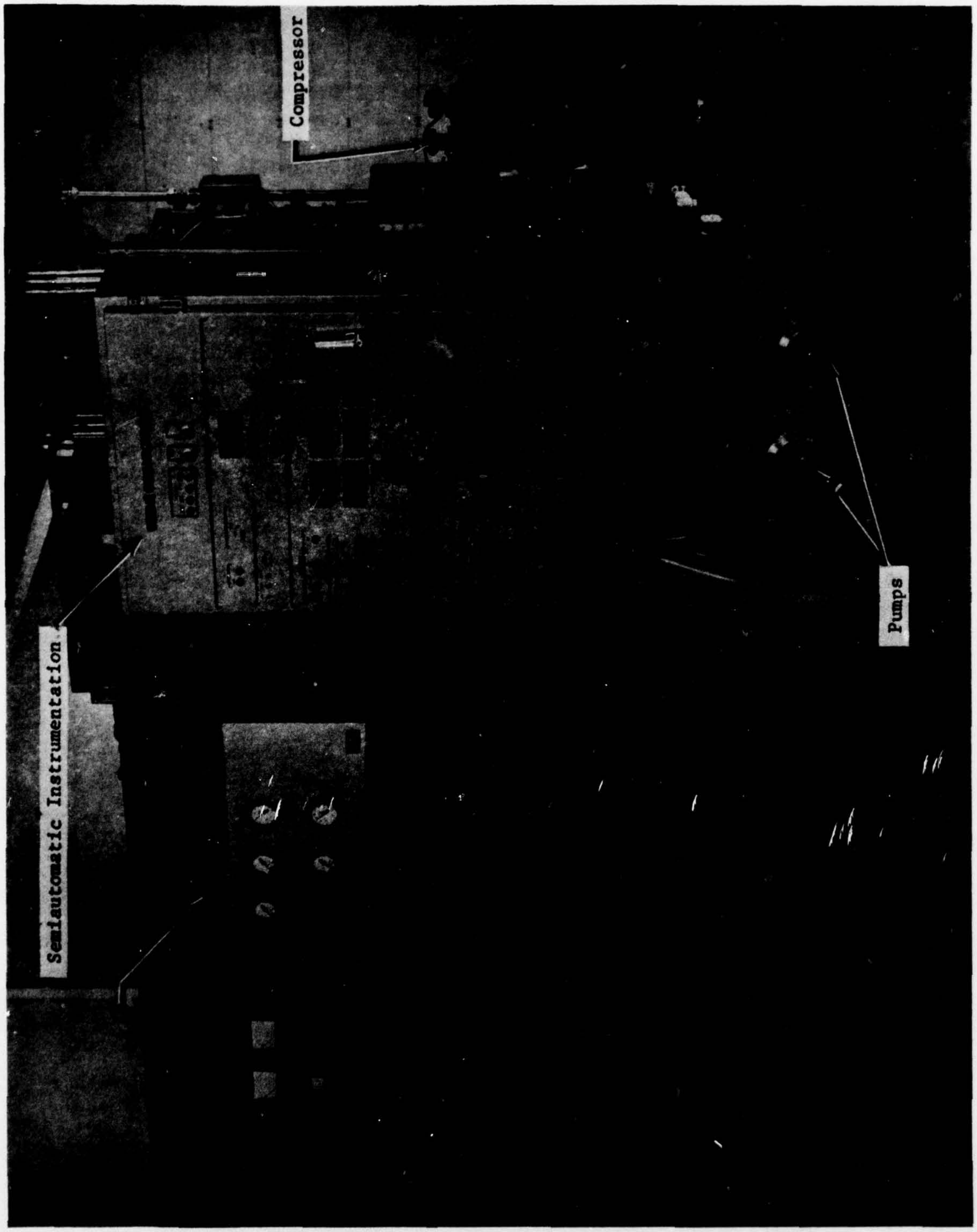


FIGURE 11 UV/OZONE OXIDATION UNIT, FRONT VIEW

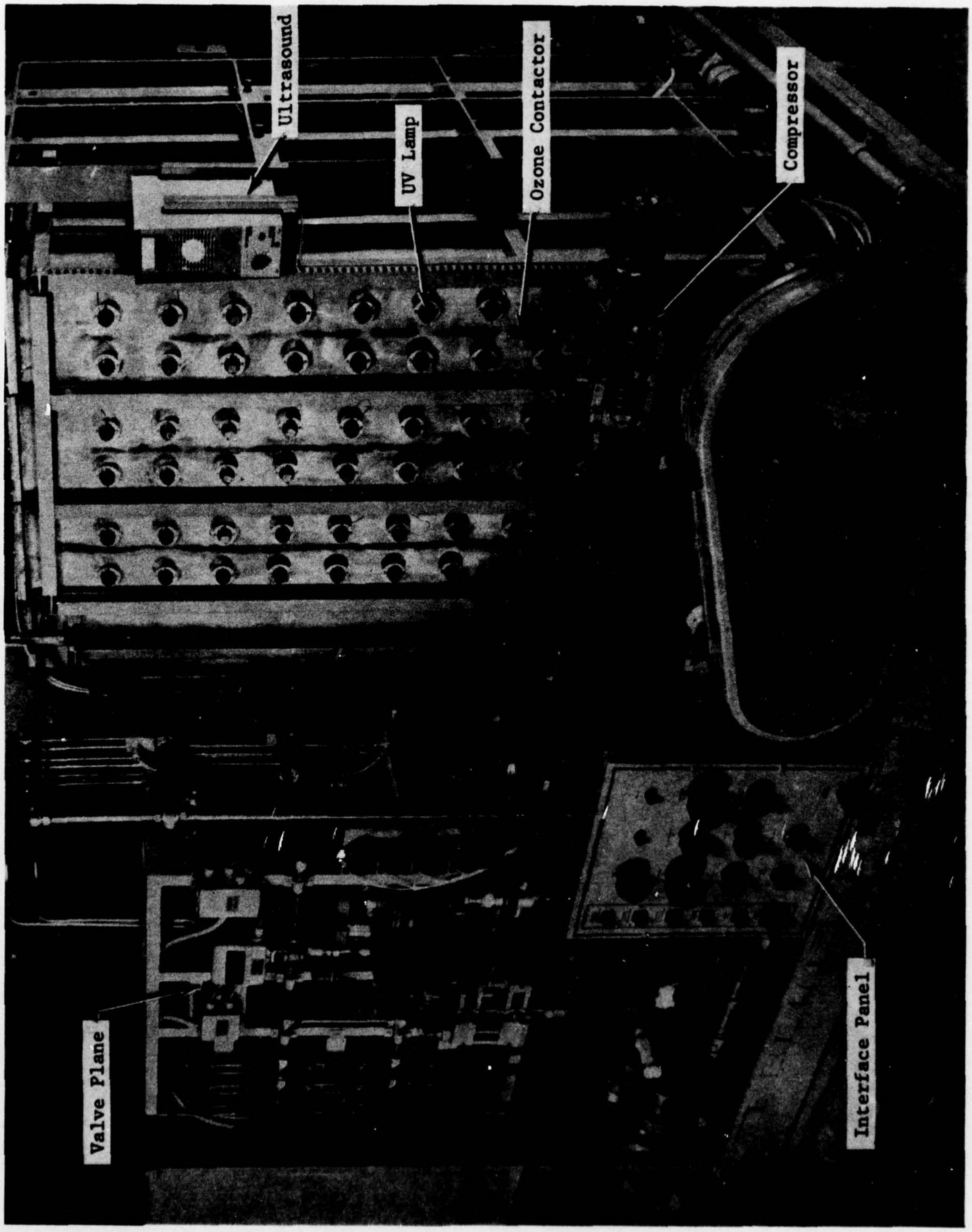


FIGURE 12 UV/OZONE OXIDATION UNIT, SIDE VIEW

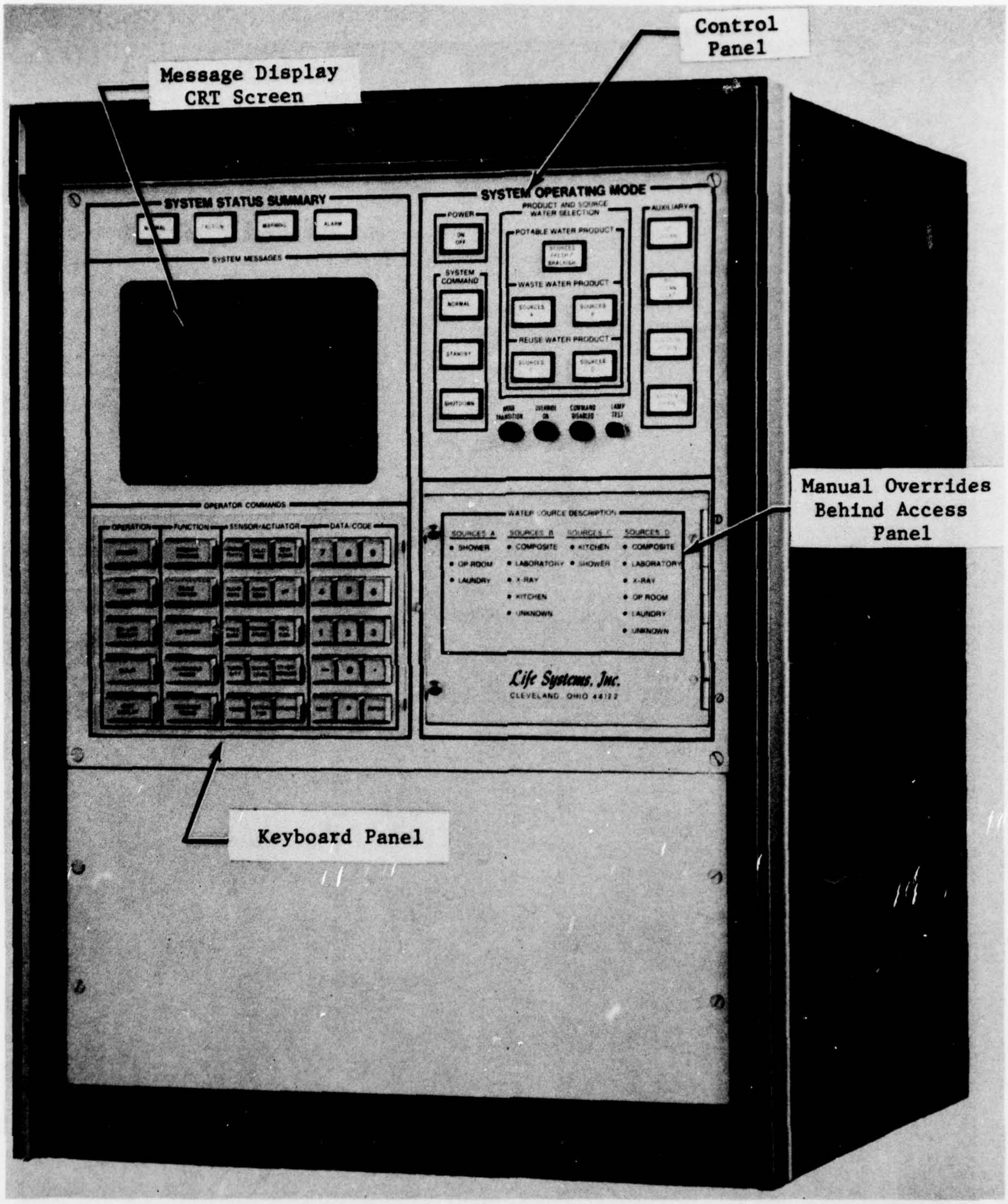


FIGURE 13 AUTOMATIC INSTRUMENTATION UNIT, FRONT PANEL

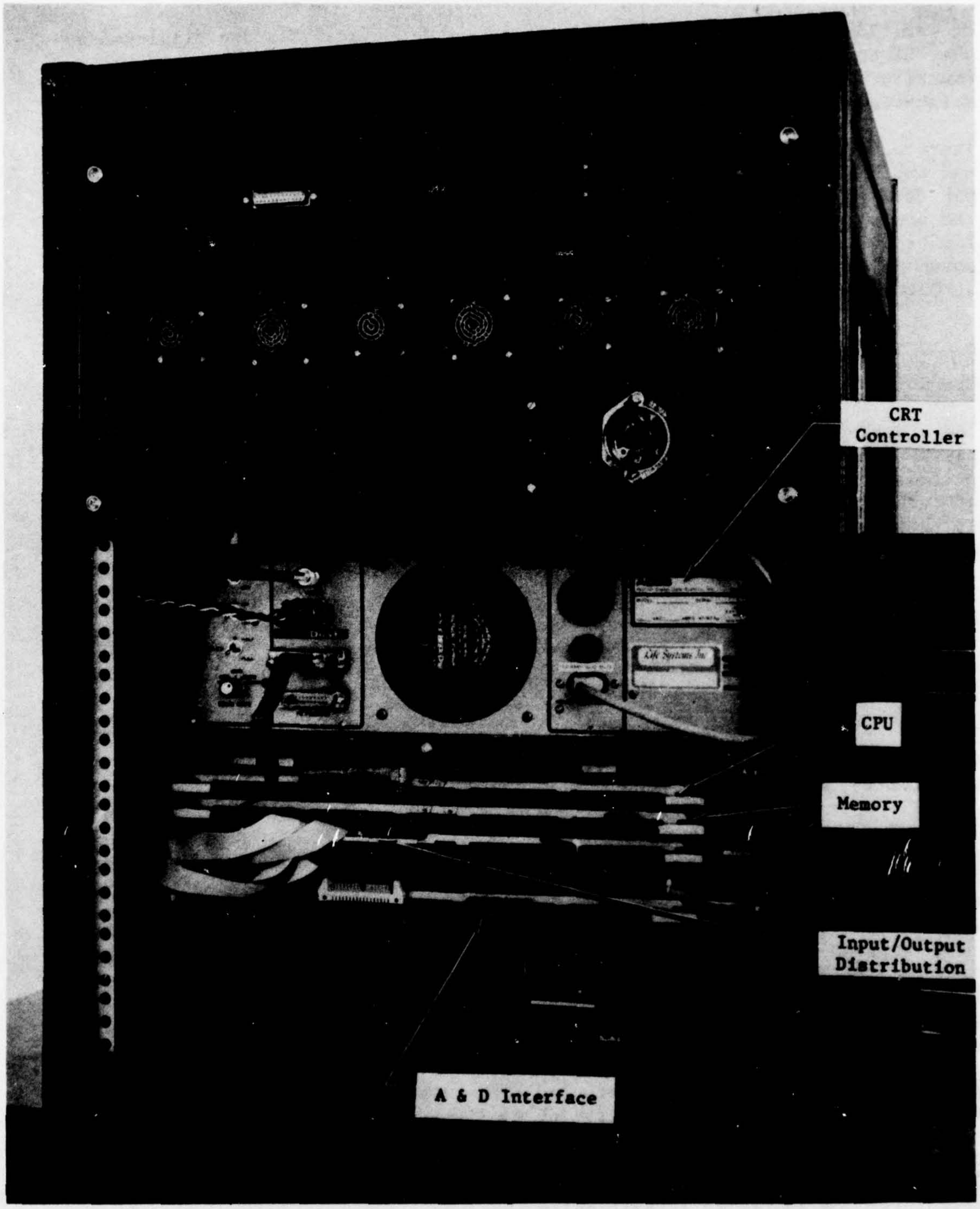


FIGURE 14 AUTOMATIC INSTRUMENTATION UNIT, REAR PANEL

of fault detection, isolation and performance trend analysis are displayed on the CRT screen. Manual override switches on a recessed panel are used to manually control 39 major components of the WPS, such as pumps and valves, for maintenance and the flexible pilot plant operation.

There are two communication links between the Automatic Instrumentation Unit and the DAS. One link is through the distributed input/output channel to the DAS foreground computer for on-line data communication and the other is through the communication switch of the DAS background computer to remote terminals for troubleshooting and debugging. The analog and digital interface board shown in Figure 14 is designed to handle 64 analog sensors, eight analog actuators, 128 digital sensors and 64 digital actuators.

Operation and Maintenance

Operation

The WPS is protected from illegal operation by unauthorized personnel. A password is required to operate the control panel. The password is a valid four-digit code preprogrammed for the identification of an operator. Before attempting to operate the system all manual override switches should be placed at their AUTO positions and the COMMAND ENABLED/DISABLED switch on the rear panel (Figure 14) should be set at the ENABLED position.

To start the operation, the valid password should be entered first through the keyboard. The start up and operation of the WPS is accomplished by depressing the NORMAL button after the wastewater source (Table 1) is selected. Detailed descriptions and operations of the control switches, the keyboard panel and the message display screen can be found elsewhere.[13,18]

The WPS is protected from damages which may result from any mistakes (unauthorized commands) of unskilled operators. The computer will help and lead the operator to correct his mistakes for a proper operation of the system.

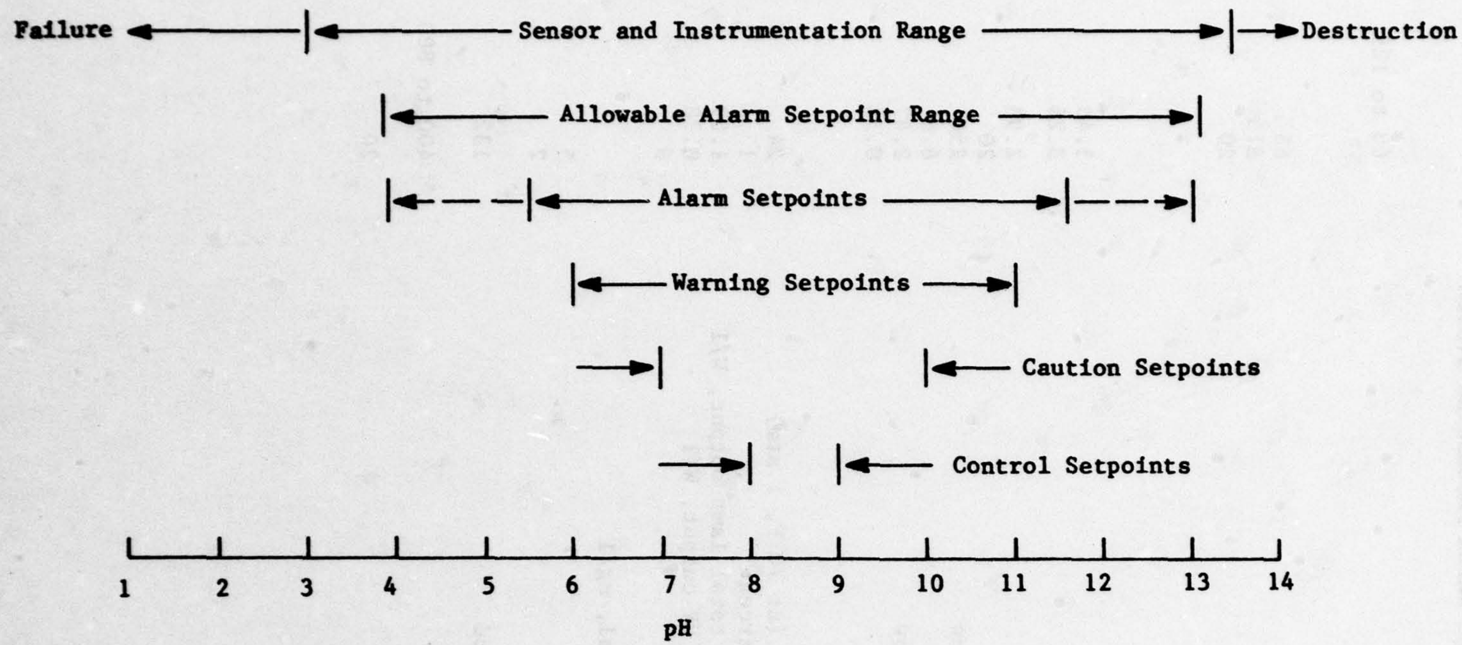
The nominal operating conditions of the WPS are summarized in Table 3. The pressures of the feed waters to the UF and RO membranes are nominally 65 and 815 psia, respectively. The influent flow rates of the hospital wastewaters, as well as their compositions, are highly variable with time. To maintain a reasonably constant process rate the EP tank should have 400 to 800 gallons of reserve water to absorb both flow and concentration variations. The UV intensity of 1.89 W/l is defined as the total light output of UV lamps divided by the wet volume of the ozone contactor. The UV intensity, based on the actual ultraviolet output, is approximately 0.78 W/l. The WPS operates 20 hours per day.

The WPS and its operator are protected from catastrophic damages due to component failures or any abnormal operating conditions. Figure 15 illustrates the instrumentation concept employed in the WPS. There are a total of six setpoints for the monitor function in addition to two control setpoints and two allowable limits for all the setpoints. If any operating condition exceeds the alarm setpoints, the system is automatically shutdown. A total of 149 setpoints, including 32 alarm setpoints, are incorporated into the WPS.

TABLE 3 NOMINAL OPERATING CONDITIONS OF THE WATER PROCESSING SYSTEM

Operating Temperature, F	68 to 125
Operating Pressure, psia	
UF Membrane	65
RO Membrane	815
Ozone Contactor	20
Water Flow Rates, gpm	
Influent	
Hospital Wastewaters	3.43
Natural Waters	3.26
Product	2.93
UF Feed	20
UF Concentrate Recycle Flow	250
RO Feed	6.6
RO Concentrate Recycle Flow	2.47
RO Bleed	0.32
Ozone Contactor	
Ozone/Air Flow Rate, scfm (at 70 F, 1 atm)	24
Ozone Concentration, wt percent	1
UV Intensity based on the total lamp output, W/1	1.89
UV Intensity based on the UV output, W/1	0.78
Initial pH of Water	9
Free Available Chlorine Residual, mg/1	
Potable and Reuse Water	5
Discharge Water	2
Sludge Removal from EP Tank, gpd	132
Initial Charge to EP Tank, gal	400 to 800
Operating Time, hr/day	20

(a) Instrumentation Concept



(b) Number of Setpoints

	Control	Monitor: Caution	Monitor: Warning	Monitor: Alarm	Total
WTU	7	19	15	7	48
WPU	13	19	19	15	66
O_3/UV	10	9	6	10	35
	30	47	40	32	149

FIGURE 15 INSTRUMENTATION CONCEPT AND NUMBER OF SETPOINTS

Maintenance

The ultimate goal for the WPS development was to design a system essentially free of laborious and complicated manual maintenance which requires extensive knowledge and training. The WPS pilot plant design incorporates such features, wherever possible without too much sacrifice of the system weight and volume, by automating essential maintenance procedures. The only thing required for such automated maintenances is to press a button when the system notifies the operator of a need for maintenance. In the prototype WPS the complete maintenance procedures would be fully automated without requiring the attention of the operator.

The WPS has four automatic controls for maintenance: (1) UF CLEAN for UF membrane cleaning, (2) RO CLEAN COAT for cleaning and coating of the RO membranes, (3) IONEXCH REGEN for regeneration of the IE resin and backflushing of both the depth filter and the carbon column and (4) SYSTEM DRAIN for draining all water tanks. The UF membrane cleaning involves flushing the UF membranes: (1) with fresh water for 15 minutes, (2) with a warm (115-120 F) cleaning solution for 30 minutes and (3) with fresh water for 25 minutes. The RO membrane maintenance involves flushing in sequence: (1) with a cleaning solution (0.5 wt. percent Biz detergent and 1 wt. percent citric acid solution) for one hour, (2) with fresh water, (3) with a coating solution for one hour, and (4) finally with fresh water. The IE resin is regenerated in a conventional way by the use of a 10% sodium chloride (NaCl) solution.

The WTU has two basket strainers (40 mesh) installed in parallel. If one is filled with filtered solids and the pressure differential across the strainer reaches the preset value of 10 psid, water flow is automatically diverted through the other clean strainer. The strainer filled with solids should be manually replaced with a clean one before the other on line becomes loaded. Two sets of micron filters (5 and 1 micron) in the WPU are operated in the same way. The preset upper limit for the pressure differential is 30 psid for the filters in the WPU.

Routine maintenance of other components such as pumps, a compressor, valves and sensors can be found in the WPS maintenance manuals[19-21] or in the manufacturers' publications.

Highlights and Benefits of the WPS Pilot Plant

The WPS pilot plant is one of the most advanced water treatment systems in which a number of state-of-the-art technologies and more recent advances in water processing have been integrated into a compact design. It has most of the features of the prototype WPS which can be transported to a point of mission via conventional routes such as standard cargo trucks, external helicopter loads, railroad, ship or cargo aircraft. In addition to treatments of field Army hospital wastewaters and natural waters, the pilot plant also can be used as a test bed for the general purpose of water treatment.

The unit processes employed in the WPS include three recent advances in water treatment: (1) O_3/UV oxidation, (2) RO and (3) UF. The O_3/UV oxidation is a chemical treatment process in which organic impurities are oxidized by ozone

and UV light to carbon dioxide, water and other simple, low molecular weight compounds. It also can provide a 100% killing of bacteria, viruses or other known microorganisms, a complete destruction of color and odor, and an improvement of taste. Both the RO and the UF separation techniques are physical treatment processes in which a semipermeable membrane separates dissolved or suspended contaminants from permeable water. The overall efficiency of the WPS for removal of various contaminants are approximately 99%.

The pilot plant employs one of the most advanced instrumentation concepts which is highlighted by minicomputer-based automatic control and monitor and by the capability of the fault detection/isolation and performance trend analysis. Table 4 lists some of the highlights and benefits of the WPS instrumentation. A number of flexibilities such as semiautomatic instrumentation and manual overrides for major components are incorporated for pilot plant testing. The pilot plant can be operated at a remote terminal with all of its control, monitor and data acquisition benefits.

DESCRIPTION OF UNIT PROCESSES

A number of water treatment processes employed in the WPS design can be grouped into six unit processes: (1) equalization and prescreening (EP), (2) ultrafiltration (UF), (3) depth filtration and ion exchange (DF/IE), (4) reverse osmosis (RO), (5) UV/ozone oxidation (O_3/UV) and (6) hypochlorination (HC). The selection of unit processes for treating specific wastewaters and the brief descriptions of the processes are presented in this section.

Selection of Unit Processes

The five classifications of the wastewater sources for the WPS were described in Table 1. Table 5 shows the selection of unit processes for treating each category of the wastewater sources. To eliminate the conflict of using the HC in the Discharge Mode and in the Potable Mode, two HC units were built in the WPS so both the Discharge and Potable Modes can be operated at the same time. Hence, the WPS operates in either one of two modes: Reuse or Potable/Discharge.

Process Descriptions

Equalization and Prescreening

The function of the EP process is to (1) remove, by settling and screening, all large influent wastewater solids (i.e., bandages, organs, bones, fragments, paper, waste food, etc.), (2) equalize the hydraulic loading variations to result in a constant flow to the UF unit process and (3) dampen the refractory organics and biological loading fluctuations to result in a more uniform feed to the UF process.

The EP tank is divided into four compartments: a bad actor tank, a mixing zone, a clarifier section and a UF feed tank. All hospital wastewaters, except laboratory waste, flow directly into the mixing compartment of the EP tank. Since laboratory waste is high in refractory organics it is first collected in the bad actor tank. The laboratory waste is allowed to flow into the mixing compartment only when the liquid level in the bad actor tank is

TABLE 4 HIGHLIGHTS/BENEFITS OF THE AUTOMATIC INSTRUMENTATION

Minicomputer-based Automatic Instrumentation

A Single Button Startup

Automatic Shutdown Controls in Case of Emergency

Unattended Operation

Remote Operation and Monitoring

Written Communication between Operator and the System

Automatic Control of Operating Conditions

Fault Detection and Isolation Analysis

System Performance Trend Analysis

Self-Protected from the damages due to Operator Error

Only Authorized Personnel with a Valid Password can Operate the System

Semiautomatic Instrumentation and Manual Override Backup

TABLE 5 SELECTION OF UNIT PROCESSES

Unit Process	Wastewater Sources[a] A	B	C	D	E
1. Equalization/ Prescreening	(1)	(1)	(1)	(1)	
2. Ultrafiltration	(2)	(2)	(2)	(2)	
3. Depth Filtration/ Ion Exchange					(1)
4. Reverse Osmosis			(3)	(3)	(2)
5. UV/Ozone Oxidation		(3)		(4)	
6. Hypochlorination	(3)	(4)	(4)	(5)	(3)
Product Water	Discharge		Reuse		Potable

(a) Wastewater Sources -

A: Shower, Operating Room, Laundry
B: Kitchen, Laboratory, X-ray, Hospital Composite, Unknown
C: Kitchen, Shower
D: Operating Room, Lab, X-ray, Laundry, Hospital Composite, Unknown
E: Natural Fresh, Brackish

high. This has a dampening effect on the contaminant concentration fluctuation and results in a more uniform feed to the UF process. The pH adjustment in the mixing compartment induces precipitation of some dissolved solutes and increases the contaminant removal efficiencies of the UF and RO membranes. Sludge accumulated at the bottom of the tank is pumped to an incinerator once a day.

Ultrafiltration

Ultrafiltration is a membrane separation process in which a semipermeable membrane separates suspended solids and some dissolved solutes from permeable solvent. The separation occurs either by the sieving mechanism or due to the difference in the mass transfer rates through the membrane. Ultrafiltration is carried out at reasonably low pressures, typically less than 150 psia. The process has been used successfully for the treatment of a number of industrial wastewaters.

The major function of the UF process in the WPS is to remove suspended solids and turbidity from the hospital wastewaters in order to minimize the fouling and maintenance of the RO membranes. Due to the high contaminant concentration of 500-4,200 mg/l total solids in the wastewater, the permeate flux of the UF membrane is relatively low. Thus the flux is of prime concern in order to reduce volume, weight and power consumption of the WTU.

As UF processing continues, the permeate flux declines due to the solid concentration buildup in the feed and the increased concentration polarization on the membrane surface. Under such circumstances the gel-layer mass transfer rather than the membrane permeability controls the flux (the gel-layer is a layer of highly concentrated, precipitated solids, usually of high molecular weight greater than 15,000, which is formed on the active surface of the UF membrane). The permeate flux depends on both the flow velocity through the membranes and the water temperature, since they play a significant role on the gel-layer mass transfer. The UF membranes in the WPS operate in the gel-layer mass transfer-controlled regime.

Flux increases as the flow velocity through the UF membranes increases. Consequently, the volume and weight of the membrane separation system required for a given capacity decreases. However, at a higher velocity a larger pumping system and more power are required. The optimum flow rate should be determined by a trade-off between membrane costs on one hand and costs of pump and power on the other hand. For the operation of a high water recovery, the concentrate stream of the UF membranes usually must be recycled to maintain a desired flux.

The membrane permeate flux also increases very rapidly as the temperature of the process water increases. The higher flux at higher temperature may be attributed to the reduced water viscosity and probably to the reduced membrane fouling. Operating at too high temperatures, however, should be avoided due to disadvantages such as (1) greater power required for heating in the UF process and for cooling in the RO process, (2) insulation needed for the EP tank and (3) more costly high temperature resistant material.

The contaminant removal efficiency, R_m, of a membrane may be defined as:

$$R_m = 1 - C_p/C_f \qquad (1)$$

where C_p and C_f are the contaminant concentrations in the permeate stream and the feed water, respectively.

A simplified model was developed to characterize the performance of the UF process.[11] Overall material balances for a semibatch operation (one batch a day) were used to predict the system removal efficiencies and the concentration variation of a certain contaminant in the system. The results are shown below:

Contaminant	Membrane Rejection, R_m	Process Efficiency, R_o	Concentration Ratio, C_s/C_i
Suspended Solids	0.999	0.997	19.9
Turbidity	0.996	0.989	19.8
Total Solids	0.50	0.26	6.1
TOC	0.88	0.73	14.8
COD	0.90	0.76	15.6

The contaminant removal efficiencies, R_o, of the UF process vary depending on the membrane rejection and the amount of water initially charged to the EP tank. The removal efficiencies increase with the decrease of the initial charge. On the other hand, the permeate flux decreases, since the contaminant concentration in the system builds up more rapidly. An initial charge of 412 gallons of water was used for the calculations. The last column gives the ratio of the contaminant concentration in the system to that of the influent water flowing in the EP tank.

Depth Filtration and Ion Exchange

The DF/IE is a pretreatment process for purifying natural waters. The primary objective of the natural water pretreatment is to minimize the fouling and maintenance of the RO membranes while treating the natural waters. Among various foulants of the RO membranes, turbidity, suspended solids and hardness are of prime concern in the WPS operation. Suspended solids should be reduced to less than 5 mg/l and the turbidity to less than 10 mg/l before processing by RO. Hardness producing ions such as calcium and magnesium should be removed sufficiently enough to prevent the precipitation of their sulfate or carbonate salts on the RO membrane surface.

Figure 16 is a block diagram of the natural water pretreatment process, which consists of (1) a depth filter, (2) a CA column and (3) an IE column. The solid line indicates the flow path of the process water, while the dotted lines signify flow paths for backflushing and regeneration. The primary function of the depth filter is to remove suspended solids and turbidity from

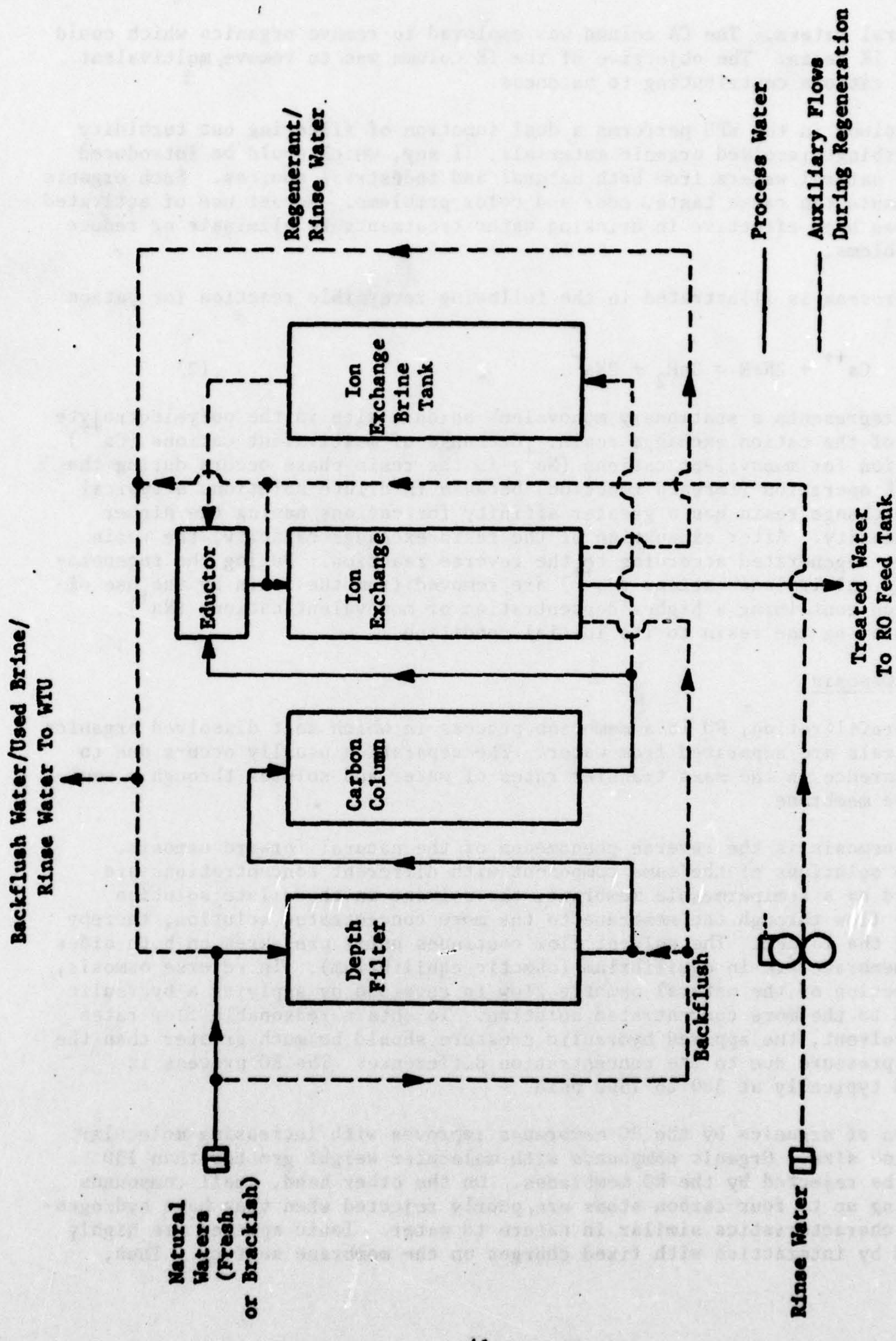


FIGURE 16 BLOCK DIAGRAM OF THE NATURAL WATER PRETREATMENT PROCESS

the natural waters. The CA column was employed to remove organics which could foul the IE resin. The objective of the IE column was to remove multivalent metallic cations contributing to hardness.

The CA column in the WPU performs a dual function of filtering out turbidity and adsorbing dissolved organic materials, if any, which could be introduced into the natural waters from both natural and industrial sources. Such organic contaminants can cause taste, odor and color problems. Recent use of activated carbon has been effective in drinking water treatments to eliminate or reduce such problems.

The IE process is illustrated in the following reversible reaction for cation exchange:

$$Ca^{++} + 2NaR = CaR_2 + 2Na^{+} \qquad (2)$$

where R represents a stationary monovalent anionic site in the polyelectrolyte network of the cation exchange resin. Exchange of multivalent cations (Ca^{++}) in solution for monovalent cations (Na^{+}) in the resin phase occurs during the normal IE operation (forward reaction) because in dilute solutions a typical cation exchange resin has a greater affinity for cations having the higher charge density. After exhaustion of the resin exchange capacity, the resin should be regenerated according to the reverse reaction. During the regeneration step multivalent cations (Ca^{++}) are removed from the resin by the use of a solution containing a higher concentration of monovalent cations (Na^{+}), thus restoring the resin to its initial condition.

Reverse Osmosis

Like ultrafiltration, RO is a membrane process in which most dissolved organics and minerals are separated from water. The separation usually occurs due to the difference in the mass transfer rates of water and solutes through a semipermeable membrane.

Reverse osmosis is the reverse phenomenon of the natural forward osmosis. When two solutions of the same component with different concentrations are separated by a semipermeable membrane, the solvent in the dilute solution tends to flow through the membrane to the more concentrated solution, thereby diluting the latter. The solvent flow continues until pressures on both sides of the membrane are in equilibrium (osmotic equilibrium). In reverse osmosis, the direction of the natural osmotic flow is reversed by applying a hydraulic pressure to the more concentrated solution. To obtain reasonable flow rates of the solvent, the applied hydraulic pressure should be much greater than the osmotic pressure due to the concentration difference. The RO process is operated typically at 300 to 1500 psid.

Rejection of organics by the RO membranes improves with increasing molecular length and size. Organic compounds with molecular weight greater than 150 tend to be rejected by the RO membranes. On the other hand, small compounds containing up to four carbon atoms are poorly rejected when they have hydrogen-bonding characteristics similar in nature to water. Ionic species are highly rejected by interaction with fixed charges on the membrane surface. Thus,

minerals, such as calcium, sodium and sulfate ions, are highly rejected. In addition, the RO membranes are known to be capable of removing biological and colloidal matter.

Performance of a RO membrane is usually characterized by its solute rejection, as defined by Equation 1, and by the permeate flux. Provided that transport of water through the membrane governs the rate of permeation, the permeate flux of water, J_p, can be related to the driving force, delta P, by

$$J_p = K \frac{(\Delta P)^n}{\mu\delta} \qquad (3)$$

where
μ = viscosity of water
δ = membrane thickness,
K = permeability of the membrane, and
n = constant.

The driving force, delta P, is defined by:

$$\Delta P = (p_c - p_p) - (\pi_c - \pi_p) \qquad (4)$$

where p is the hydraulic pressure, π is the osmotic pressure and the subscripts c and p signify the concentrate and the permeate stream, respectively. In a dilute, ideal solution, the osmotic pressure can be approximated as:

$$\pi \cong cRT \qquad (5)$$

where
c = solute concentration,
R = gas constant, and
T = absolute temperature.

Modular membrane systems either for RO or UF separation can be designed to operate in one of several process configurations, i.e., semibatch, once-through continuous, recycle-and-bleed continous, stages in series, stages in parallel, etc. Three common system designs and their descriptions were presented in a previous report.(11) In order to achieve a high product recovery (90%) and to maintain a desired flux, a recycle-and-bleed mode of the RO operation was selected in a staged arrangement of membranes.

Both the contaminant removal efficiency and the permeate flux of the RO membrane depend on the product water recovery. At a fixed product recovery the membrane permeate flux increases as the water temperature and the pressure differential across the membrane increase.

The contaminant removal efficiencies of the RO membrane used in the WPS are summarized(3) below for both the hospital composite waste and the natural brackish waters:

- Hospital Composite Waste

Contaminant	Average Removal Efficiency, %
Total Solids	98
Conductivity	98
TOC	76
COD	76
Surfactants	97
Chloride Ion	98
Ammonia	47
Urea	86

- Natural Brackish Waters (Table 6)

Contaminant	Average Removal Efficiency, %
Total Solids	73 - 98
Chloride Ion	70 - 97
Nitrate-Nitrogen	65 - 85
Sulfate	88 - 99+

UV/Ozone Oxidation

The hospital wastewaters contain a variety of toxic chemical compounds (for details see Appendix 4). The UF and RO processes are capable of reducing the concentration of many of these compounds to low levels (30 mg/l TOC and 108 mg/l COD for the hospital composite). The processed reuse water must be essentially free of organics and inorganics which might be detrimental to man. A concentration level of 5 mg/l TOC and 10 mg/l COD has been suggested as an appropriate water quality specification. The O_3/UV has been demonstrated to be one of the most viable and cost-effective means of polishing the RO permeate to meet the required TOC and COD levels as established for the allowable concentration limits.[3,4]

The main objective of the O_3/UV process in the Reuse Mode of the WPS operation is to reduce TOC from 30 mg/l to less than 5 mg/l (84% removal) and to reduce COD from 108 mg/l to less than 10 mg/l (91% removal). In addition, the O_3/UV process accomplishes disinfection (100% kill) and complete removal of color and foam.

The O_3/UV of the hospital wastewaters is a heterogeneous system in which ozone in the gas phase is contacted with organics in the liquid phase. At the ordinary test conditions organics may be assumed to be insoluble in the gas phase, hence, reactions occur in the liquid phase and ozone has to be dissolved in liquid to react with the organics.

When irradiated by UV light, dissolved ozone in an alkaline aqueous solution[22] appears to decompose to hydroxyl radicals mostly by the following reactions.

$$O_3 + h\nu \rightarrow O_2^* + O^* \qquad (6)$$

$$O^* + H_2O \rightarrow 2OH^\cdot \qquad (7)$$

where * indicates an excited state. The hydroxyl radical ($OH^\cdot$) which has a higher oxidation potential than ozone is very reactive and seems to play a major role in the succeeding oxidations of organics. The hydroxyl radicals thus formed are then consumed on a competitive basis either for the oxidation of organics or for the radical-radical reactions.

The reaction mechanism for the organic oxidation is not known. It has been suggested that the hydroxyl radicals may undergo hydrogen abstraction reactions with aliphatic compounds. The resulting organic radical may react further to produce an alcohol:

$$RH + OH^\cdot \rightarrow R^\cdot + H_2O \qquad (8)$$

$$R^\cdot + OH^\cdot \rightarrow ROH \qquad (9)$$

In successive abstraction of hydrogens, addition of hydroxyl radicals or oxygen (which is present almost in any ozonation system) and rearrangement of unstable intermediates, alcohols may be oxidized through aldehydes to acids, as the experimental data by Chian and Kuo[7] for the O_3/UV of methanol suggest. They identified formaldehyde (HCHO) and formic acid (HCOOH) as the intermediate products for the O_3/UV of methanol. Further oxidation of acids would result in decarboxylation to produce carbon dioxide and water. The oxidation of methanol therefore may proceed as follows:

$$CH_3OH \xrightarrow[h\nu]{OH} HCHO \xrightarrow[h\nu]{OH} HCOOH \xrightarrow[h\nu]{OH} CO_2 + H_2O \qquad (10)$$

Chemical oxygen demand is naturally reduced as the oxidation proceeds. However, no TOC reduction is realized until decarboxylation occurs.

Under the previous[4] and present program supported by the USAMRDC the reaction kinetics and a mathematical modelling of the O_3/UV have been developed to design a reactor for the WPS. The following variables have been identified as affecting the overall rate of the O_3/UV:

- TOC concentration
- Intensity of UV light
- Ozone concentration in feed gas
- Feed gas flow rate
- Temperature, pressure and pH

Experimental results indicated that the overall reaction under the WPS design conditions proceeds through three phases with different rates.[22] In phase II the reaction is first-order with respect to the TOC concentration and 1.5th-order with respect to the ozone partial pressure. It also has 1.5th-order dependence on the gas superficial velocity. The effect of UV light activation becomes more significant as the reaction proceeds. The effects of temperature, pressure and pH on the overall reaction rate were not significant under the operating conditions of the WPS O_3/UV unit. Further details on the O_3/UV process were published in a separate report.[14]

Hypochlorination

Hypochlorination in the WPS is the last process of a treatment train for any reuse, potable, or discharge water production. In a treatment train including the O_3/UV process, almost complete destruction of bacteria, viruses or any other microorganisms is accomplished. However, the product water of the O_3/UV process has a low level of dissolved ozone residual, typically less than 0.3 mg/l, and the dissolved ozone readily decomposes with a half-life less than one hour. It is expected that the dissolved ozone alone will do little to protect the product water from possible reinfection in the water distribution line.

The main objective of the HC unit in the WPU is to accomplish disinfection of the potable water and to provide a precautionary protection for possible reinfection of the reuse water in the distribution line. The function of the HC unit in the WTU, however, includes disinfection of the discharge water which is not treated in the O_3/UV Unit. The HC is one of the conventional chlorination practices which uses a calcium hypochlorite solution instead of hazardous chlorine gas. The two HC units in the WPS provide a minimum free-chlorine residual of 2 mg/l in the discharge water and 5 mg/l in the reuse or potable water. The hypochlorite dose rates are automatically controlled to maintain the desired chlorine levels.

WATER PROCESSING SYSTEM DESIGN

The WPS has been designed to be a fully automated, integrated water treatment system which can produce: nonpotable reuse water from nonsanitary hospital wastewaters and potable water from natural fresh or brackish water while treating the hospital wastewaters for safe discharge to the environment. In addition, the system has a pilot plant capability for scientific data development as well as field and transportable characteristics of low weight, low volume, low power consumption, maintainability and compact design.

Wastewater Characteristics

The WPS has to treat waters obtained from two sources. One is the nonsanitary wastewaters generated in the functional areas of a field Army medical facility such as operating room, laboratory, kitchen, laundry and shower room. The other is the natural waters which may be either fresh or brackish (Table 1).

Hospital Wastewaters

There are two types of composite wastes in the nonsanitary wastewaters produced from the field Army medical facilities. One is the hospital composite waste consisting of shower (51%), operating room (26%), kitchen (12%), laboratory (8%), and X-ray waste (3%). The other type is the laundry composite waste consisting of 67% Type I (color-fast) and 33% Type II (woolens). The WPS treats both types of composite wastes in addition to individual wastes.

The compositions of simulated MUST hospital wastewaters are presented in Appendix 4. In reality, the flow rate and composition of the individual waste stream are expected to vary substantially from day to day as well as from hour

to hour. The simplified flow schedule for the hospital composite waste has been developed[1] and is presented in Figure 17.

Natural Waters

The anticipated quality of the brackish waters in the U.S. was shown in Table 6. The values were taken from the field analysis data[3] on three surface water samples (Buckeye, Arizona; Denver, Colorado; Rogers Springs, Nevada) and from data obtained from the AAI Corporation (Baltimore, MD). The quality of the fresh waters is expected to be much better than that of the brackish waters.

Design Specifications

The WPS design specifications are shown in Table 7. The WPS was sized to treat 4,118 gal/day of the hospital wastewaters and 3,900 gal/day of the natural waters. The overall product recoveries are 90% for potable water, 85% for reuse water and 95% for discharge water. The product waters for potable and reuse should meet the water quality specifications presented in Table 8. The product waters should have the specified free residual chlorine levels for disinfection. The WPS is to be operated 20 hours per day with the rest of the day available for routine maintenance.

The unique requirements for the WPS design are:

1. Limited allowance on dimensions, weight and power consumption for transportation and field applications.

2. Automatic instrumentation and minimum maintenance for unskilled operators.

3. Pilot plant capability and semiautomatic instrumentation for performance evaluation and scientific data development.

System Design

The major processes employed in the WPS for water treatment and purification are membrane separation, adsorption and ion exchange, and chemical oxidation by ozone and chlorine. Highlights of the WPS design will be briefly described in the following subsections.

Water Treatment Unit

The flow schematic of the WTU is shown in Figure 18. The hospital wastewaters from the field Army medical complex facilities are fed to the EP tank where hydraulic loading and concentration variations are equalized to result in a more uniform feed to the UF membranes. The wastewaters are then pumped through a 40-mesh basket strainer and a heat exchanger to the UF membrane assembly in which suspended solids and other contaminants are separated from the process water stream. The permeate stream of the UF assembly is finally fed to the WPU in the Reuse mode, or to the O_3/UV unit for wastewater Source B (see Table 1) in the Discharge mode, or to the HC unit for wastewater Source A in the Discharge mode.

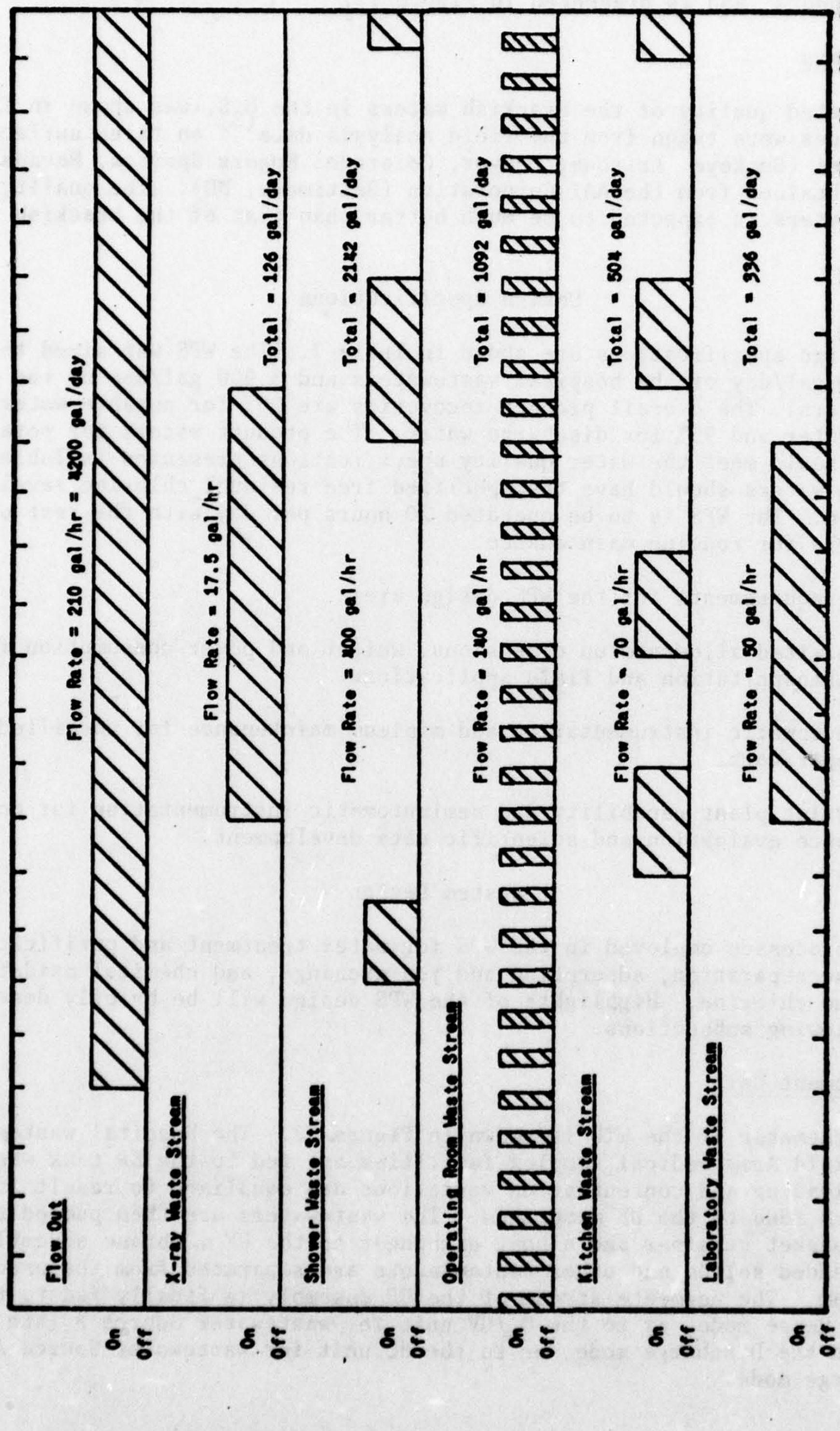


FIGURE 17 SIMPLIFIED FLOW SCHEDULE FOR THE MUST HOSPITAL COMPOSITE WASTE

TABLE 6 ANTICIPATED WATER QUALITY FOR U. S. SURFACE WATERS

Contaminants	Concentration mg/l
General	
Total Dissolved Solids, mg/l	1,800-3,200
Suspended Solids, mg/l	10-100
Turbidity, NTU	5-200
Conductivity, μmhos/cm	2,000-9,000
pH Value	6-9
Hardness (as $CaCO_3$), mg/l	200-2,000
Metals	
Calcium, mg/l	50-500
Copper, mg/l	0-2.0
Iron, mg/l	≤ 1
Magnesium, mg/l	20-200
Sodium, mg/l	300-1,200
Potassium, mg/l	1-30
Manganese, mg/l	0-1.5
Nonmetals	
Bicarbonate or Carbonate, mg/l	100-500
Chloride, mg/l	300-1,500
Nitrate-Nitrogen, mg/l	5-50
Total Phosphate, mg/l	0-20
Suflate, mg/l	100-1800
Bromide, mg/l	0-10
Fluoride, mg/l	0-10
Miscellaneous	
Silica, mg/l	5-50
Hydrogen Sulfide, mg/l	Trace

TABLE 7 WATER PROCESSING SYSTEM DESIGN SPECIFICATIONS

Dimensions (Length x Width x Height)[(a)]	
Expanded, ft	11.5 x 9.5 x 6.75
Transportable, ft	11.5 x 6.5 x 6.75
Dry Weight, lb	Max. 6,500 Each Ward, Including the Ward Container
Power Consumption,[(b)] kW	Max. 30 for total WPS
Wastewater Source	Field Hospital Wastes, Natural Fresh or Brackish Water
Treatment Capacity,[(c)] gpd	
Hospital Wastes	4,118
Natural Waters	3,900
Product Capacity,[(c)] gpd	
Reuse and Potable Waters	3,500
Discharge Water	3,900
Overall Product Recovery, %	
Potable	90
Reuse	85
Discharge	95
Influent Water Quality	See Table 6 and Appendix 4
Product Water Quality	
Potable and Reuse Waters	See Table 8
Discharge Water	Equivalent to "Secondary Treatment
Free Residual Chlorine Level, mg/l	
Potable and Reuse Waters	≥ 5
Discharge Water	≥ 2
Operating Time, hr/day	20
Instrumentation	Auto and Semiauto

(a) Inside dimensions of a Single Ward Container for either the WTU or the WPU.
(b) Desirable combined 60 Hz and 400 Hz power.
(c) Capacities for a 20 hr/day operation.

TABLE 8 POTABLE AND REUSE WATER SPECIFICATIONS[23]

Contaminant	Maximum Water Quality Standards mg/l (unless otherwise stated)
Total Organic Carbon	5.0
Chemical Oxygen Demand	10.0
Alkyl Benezene Sulfonate	0.5
Ammonia (NH_3)	0.5
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chloride	600.0
Chromium (hexavalent)	0.05
Copper	1.0
Cyanide	0.2
Fluoride	4.0
Iron	0.3
Lead	0.05
Magnesium	150.0
Manganese	0.05
Nitrate - Nitrogen	10.0
Phenolic Compounds	0.001
Selenium	0.01
Silver	0.05
Sulfate	400.0
Total Solids	1500.0
Color	50.0 Units

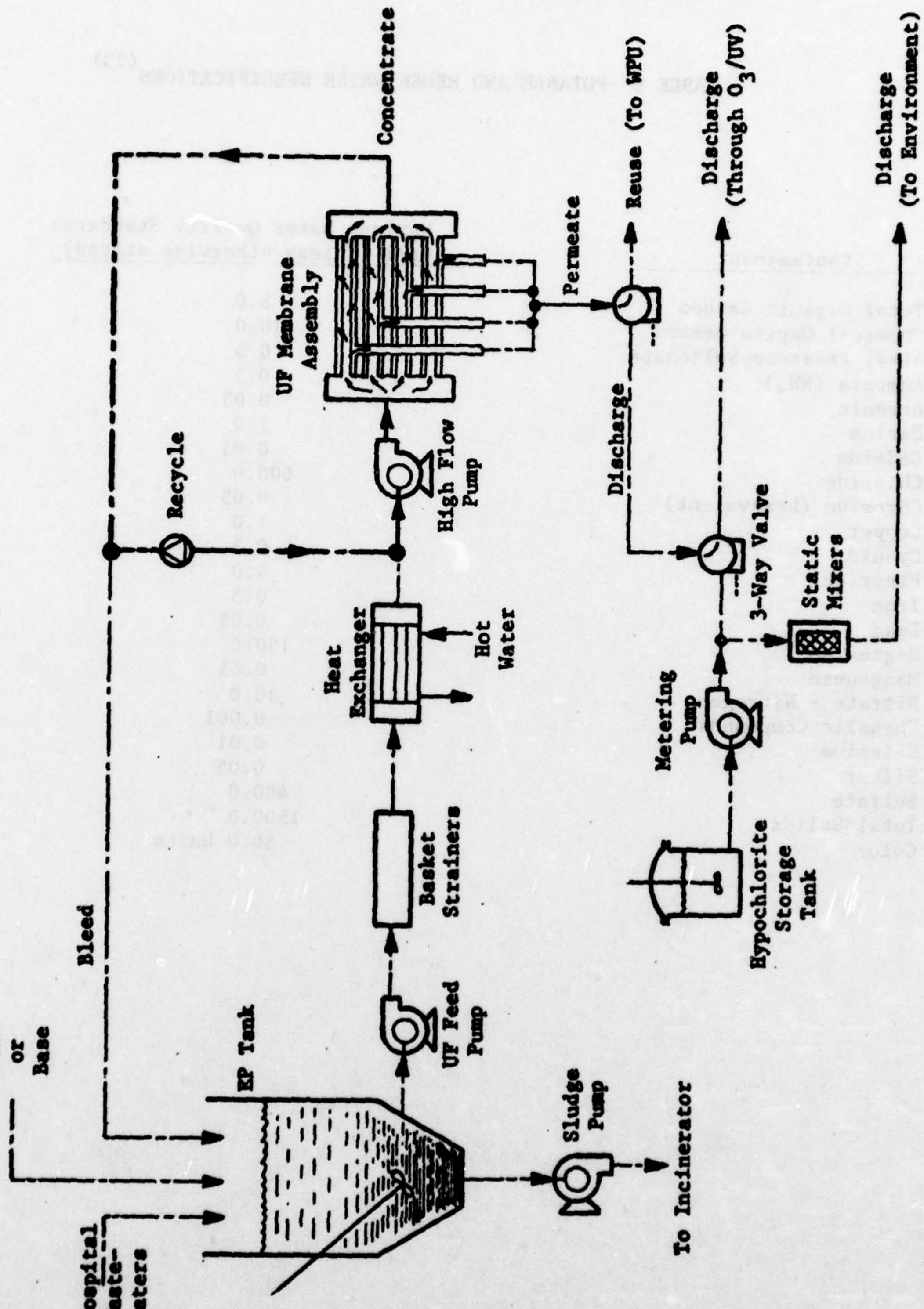


FIGURE 18 FLOW SCHEMATIC OF WATER TREATMENT UNIT

The EP tank schematically shown in Figure 19 has a wet volume of 1,320 gallons and is divided into four compartments: (1) a bad actor tank (224 gallons), (2) a mixing zone (134 gallons), (3) a clarifier section (883 gallons) and (4) a UF feed tank (80 gallons). All wastewaters, except laboratory waste, are collected in the mixing compartment where the pH is adjusted to about 8 by adding *either acid (2N sulfuric (H_2SO_4)) or base (2N sodium hydroxide (NaOH))*. Since the laboratory waste is high in refractory organic concentration, it is collected separately and equalized in the bad actor tank before being allowed to overflow to the mixing compartment. The four compartments are interconnected through holes on the dividing walls. Sludge accumulated at the bottom of the clarifier section is scheduled to be removed automatically once every day during the four-hour maintenance period. The sludge pump is programmed to operate for 12 minutes at a pumping rate of 11 gpm.

The UF feed pump feeds the wastewater to the UF circulation loop at a rate of approximately 20 gpm. The high flow pump feeds both the recycle and feed water to the UF membranes at a rate of 270 gpm. The UF membrane assembly consists of nine modules which are installed in parallel. Each module has eight UF membranes in series. The total surface area of the 72 membranes installed in the UF assembly is 158 ft^2. The flow rate of the UF permeate varies with the operating conditions and the wastewater characteristics. Only the wastewater temperature is controlled by a heat exchanger to maintain the permeate flow above the required minimum of 3.26 gpm. A small portion of the recycle flow is bled to the EP tank to maintain a constant recycle flow rate.

The function of the HC unit is to maintain 2 mg/l free-residual chlorine in the discharge water for disinfection. In order to maintain the required chlorine level, a 7% calcium hypochlorite solution, stored in a 50 gallon polyethylene tank, is metered by a metering pump and mixed with the UF permeate in static mixers. The flow rate of the hypochlorite is automatically controlled in a feed-forward mode by means of an upstream flow sensor and pump control logic.

Water Purification Unit

The flow schematic of the WPU is shown in Figure 20. Depending on the mode of operation, there are two streams of feed water to the RO feed tank: (1) hospital wastewaters treated in the WTU (Reuse Mode) and (2) natural waters being treated in a depth filter, a carbon column and an IE resin column (Potable/Discharge Mode). The water collected in the RO feed tank is then pumped through two heat exchangers and a series of 5- and 1-micron filters to the RO membrane assembly. The concentrate stream of the RO membrane assembly is recycled through a backpressure regulator and static mixers to the feed tank. A portion of the concentrate stream is bled to an incinerator in order to control the concentration buildup of contaminants in the system. The permeate stream of the RO membrane assembly is fed either to the O_3/UV unit in the Reuse Mode or to the HC unit in the Potable/Discharge Mode. The HC unit is identical to that used in the WTU and is used to maintain 5 mg/l free-residual chlorine in the potable and reuse water for disinfection.

Natural water pretreatment consists of depth filtration, carbon adsorption and ion exchange. Both the carbon column and the depth filter are 4.5 ft high

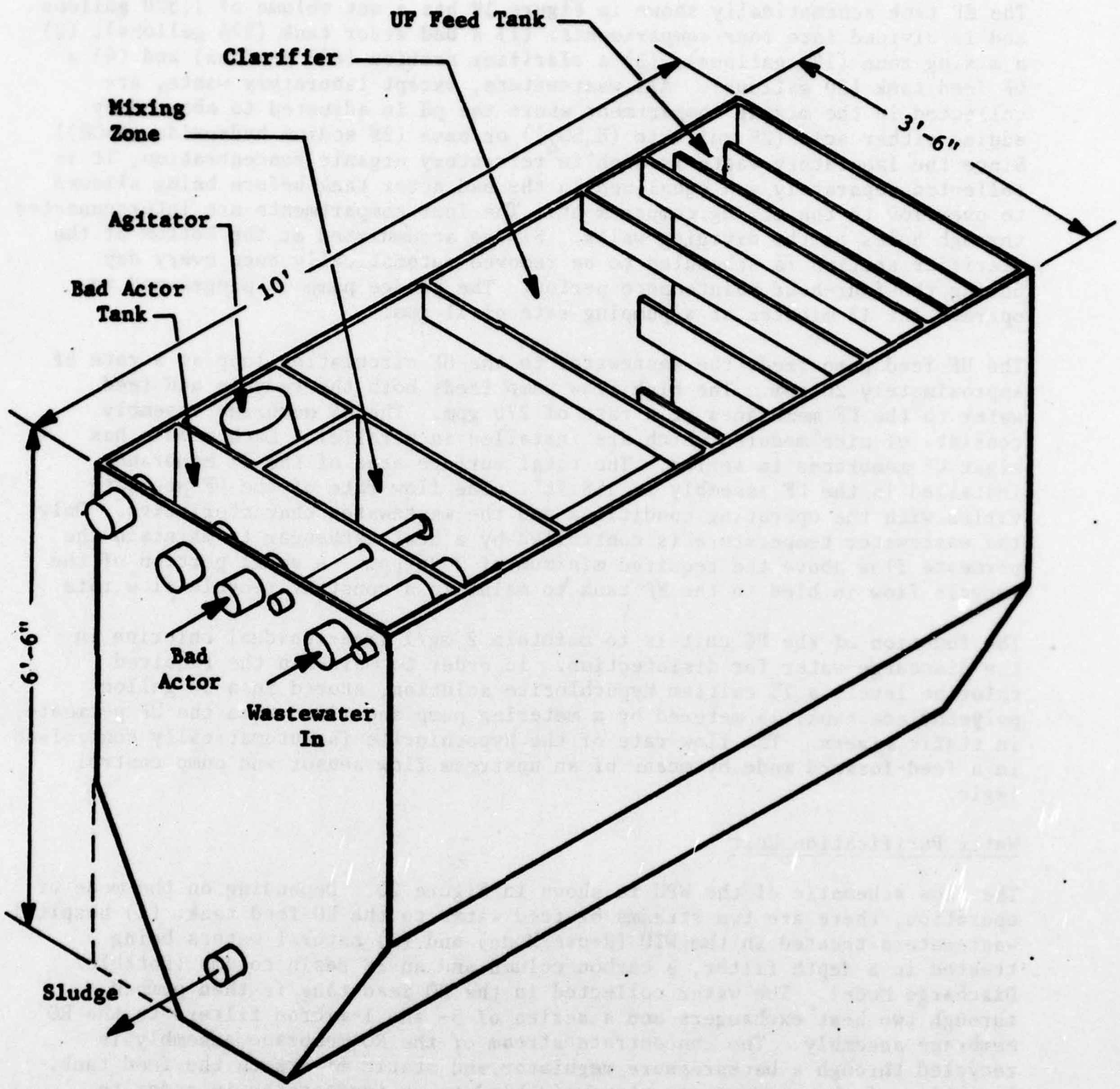


FIGURE 19 EQUALIZATION TANK

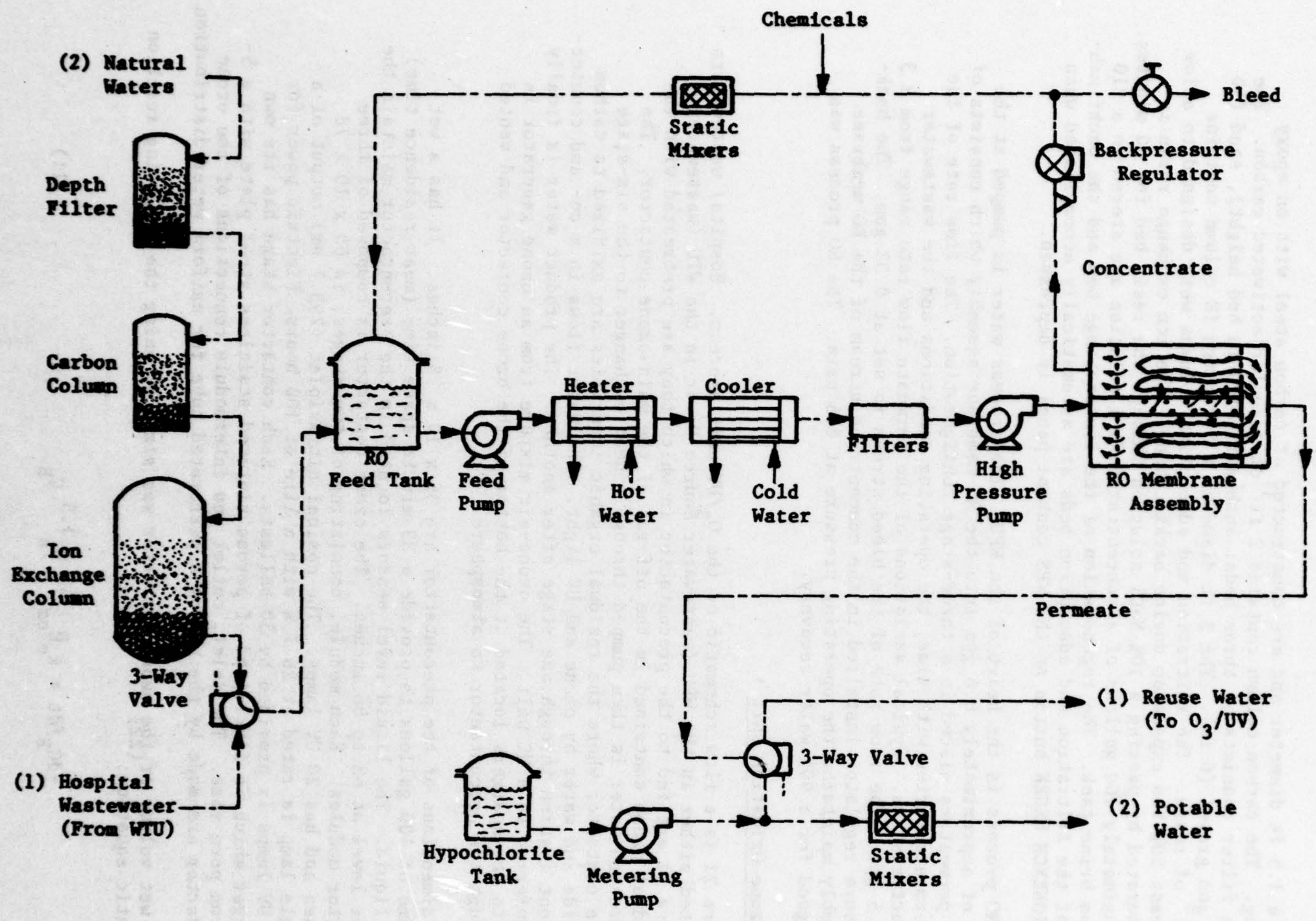


FIGURE 20 FLOW SCHEMATIC OF WATER PURIFICATION UNIT

with a 1.5 ft diameter and are constructed of carbon steel with an epoxy lining. The carbon column contains 2 ft^3 of granular activated carbon. The depth filter consists of three beds: anthracite (20-in bed height), sand (10 in), and gravel (6 in). The 3 ft diameter x 5 ft high IE column contains 21 ft^3 of resin. The filtration and adsorption columns were designed to allow at least 50% bed expansion during backflushing. The ion exchange resin is regenerated by passing a 10% NaCl solution through the resin bed for 30 minutes. Approximately 100 gallons of a concentrated NaCl solution are stored in a 210 gallon brine tank. The regeneration of the ion exchange bed and the backflushing of the filtration and adsorption beds are automatically accomplished when the IONEXCH REGEN button on the WPS control panel is depressed.

The RO process is the heart of the WPU. The process water is pumped at the rate of approximately 6.6 gpm into the RO membrane assembly which consists of four permeators placed in a three-stage configuration. The flow rate of the RO permeate varies with time, the operating conditions and the wastewater characteristics. Typical variations of the permeate flow rate range from 3.3 to 4.5 gpm. The flow rate of the bleed stream is set at 0.33 gpm. The back-pressure regulator installed in the concentrate stream of the RO membrane assembly maintains the operating pressure at 815 psia. The RO process was designed for a 90% water recovery.

UV/Ozone Oxidation Unit

Figure 21 is a flow schematic of the O_3/UV unit process. Hospital wastewaters treated either in the WPU (wastewater Source D) or in the WTU (wastewater Source B) are fed to the precontactor in which they are pretreated with the residual ozone contained in the off-gas of the main ozone contactor. The pretreated water is then pumped through a heat exchanger to the six-stage ozone contactor where the residual organic impurities are oxidized to carbon dioxide and water by ozone and UV light. The water flows in a co- and counter-current fashion through one stage after another. The product water is finally transferred to a HC unit. The ozone-air mixture from an ozone generator is fed to the spargers located at the bottom of the ozone contactor and vented through the precontactor to atmosphere.

The dimensions of the precontactor are 36 x 10 x 78 inches. It has a wet volume of 100 gallons to provide a 33 minute space time (mean residence time) for liquid. The liquid level sensors located in the precontactor maintain the water level at 63 to 66 inches. The ozone contactor is composed of three reactor modules. Each module, consisting of two stages, is 60 x 10 x 78 inches and has 20 UV lamps. The nominal ultraviolet (253.7 nm) output of a single lamp is rated at 26.7 W with a life of 100 hours. Electric power for the UV lamps is provided by 30 ballasts. Each contactor stage has its own sparger which is fabricated of porous sintered stainless steel plate with a 5-micron pore size. The inlet, outlet and intermodule connections of the ozone contactor are made by the use of a perforated tube for uniform water distribution.

The wet volume of the ozone contactor was sized by using the following reaction kinetic equation:[22]

$$-dC_B/dt = k_o \bar{P}_{oz}^{\,1.5}\, V_s^{\,1.5}\, C_B \qquad (11)$$

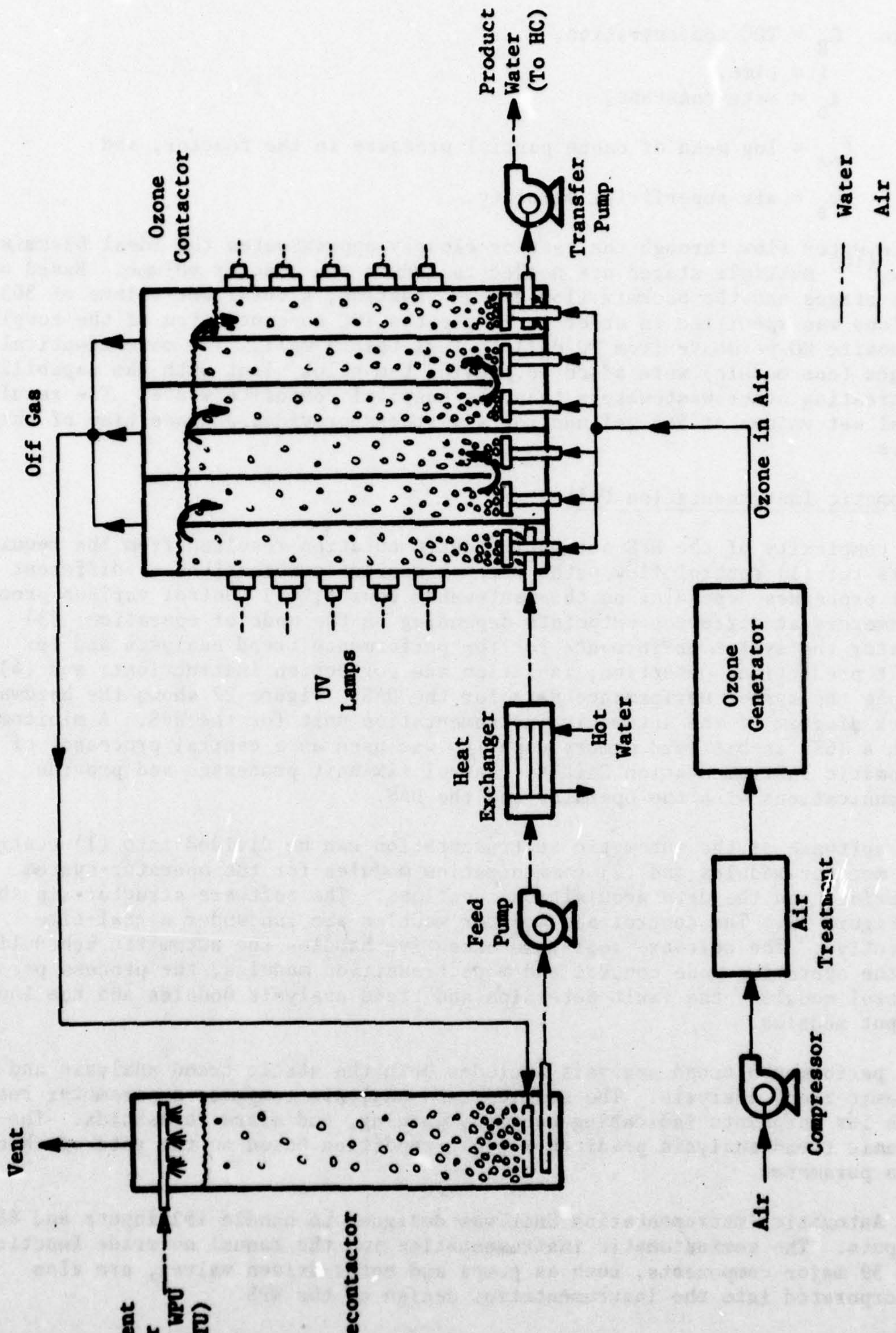


FIGURE 21 FLOW SCHEMATIC OF UV/OZONE OXIDATION UNIT

where C_B = TOC concentration,

t = time,

k_o = rate constant,

$\bar{P}_{oz}$ = log mean of ozone partial pressure in the reactor, and

V_s = air superficial velocity.

Since water flow through the reactor closely approximates the ideal backmix flow,[10] multiple stages are needed to reduce the reactor volume. Based on four stages and the backmix flow design equation, a total wet volume of 363 gallons was specified in order to reduce the TOC concentration of the hospital composite RO permeate from 30 mg/l to less than 5 mg/l. Two more identical stages (one module) were added to provide the pilot plant with the capability of treating other wastewaters than the hospital composite waste. The resulting total wet volume of 544 gallons for six stages provides a space time of three hours.

Automatic Instrumentation Unit

The complexity of the WPS automatic instrumentation resulted from the requirements to: (1) control flow paths through various combinations of different unit processes depending on the wastewater source; (2) control various process parameters at different setpoints depending on the mode of operation; (3) monitor the system performance for the performance trend analysis and for fault prediction, detection, isolation and correction instructions; and (4) sample the system performance data for the DAS. Figure 22 shows the hardware block diagram of the automatic instrumentation unit for the WPS. A minicomputer with a 16K, 16-bit word memory capacity was used as a central processor of the Automatic Instrumentation Unit to control six unit processes and provide communications with the operator and the DAS.

The software of the automatic instrumentation can be divided into (1) control and monitor modules and (2) communication modules for the operator-system interface and the data acquisition functions. The software structure is shown in Figure 23. The control and monitor modules are run under a real-time executive. The software real-time executive handles the automatic scheduling of the operating mode control and mode transition modules, the process parameter control modules, the fault detection and trend analysis modules and the input/output modules.

The performance trend analysis includes both the static trend analysis and the dynamic trend analysis. The static trend analysis compares a parameter reading with its setpoints indicating caution, warning, and alarm thresholds. The dynamic trend analysis predicts a fault condition based on the rate of change of a parameter.

The Automatic Instrumentation Unit was designed to handle 192 inputs and 85 outputs. The semiautomatic instrumentation and the manual override functions for 39 major components, such as pumps and motor-driven valves, are also incorporated into the instrumentation design of the WPS.

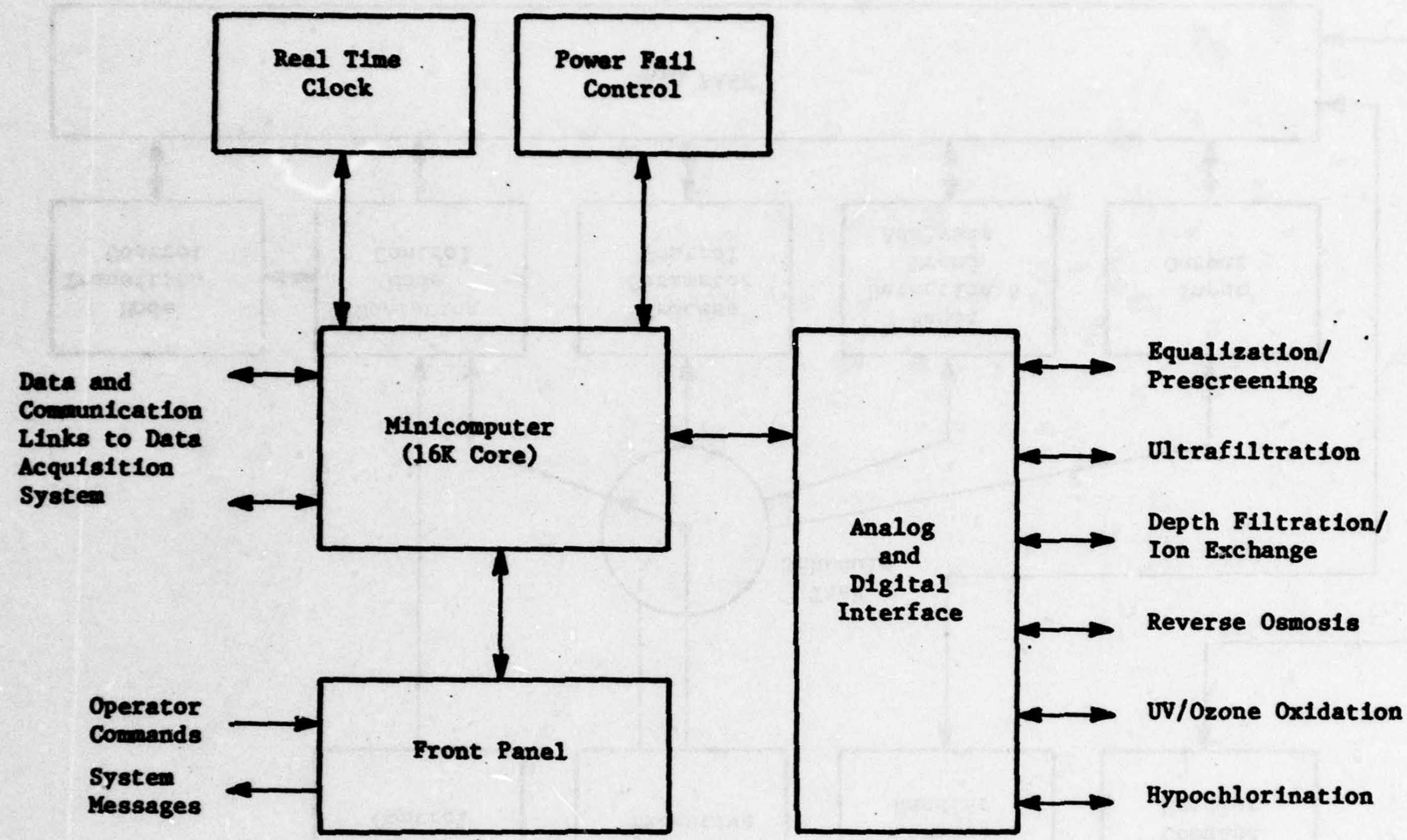


FIGURE 22 AUTOMATIC INSTRUMENTATION HARDWARE BLOCK DIAGRAM

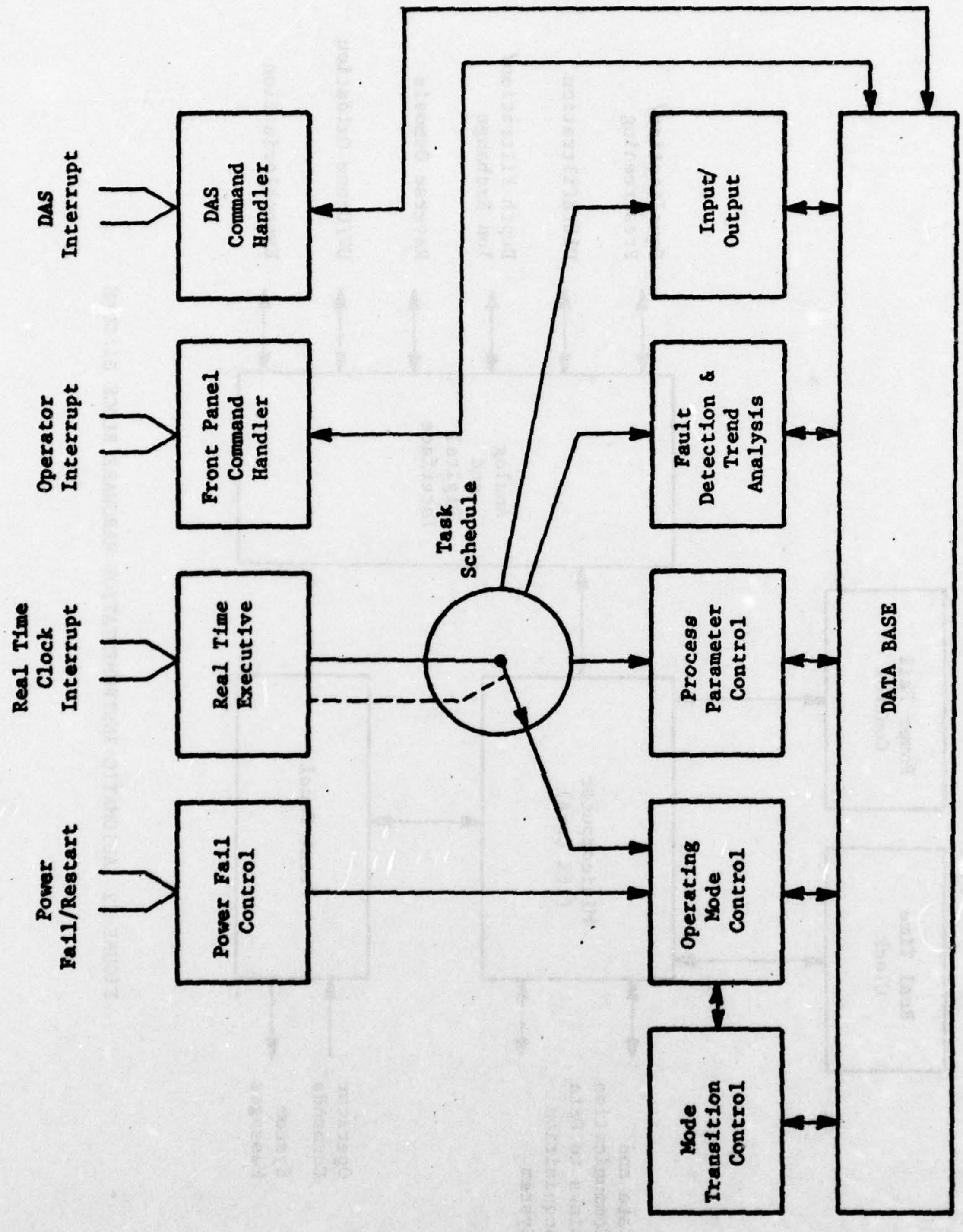


FIGURE 23 AUTOMATIC INSTRUMENTATION SOFTWARE BLOCK DIAGRAM

Design Characteristics

Table 9 summarizes the major characteristics of the WPS design. In addition to the treatment of field Army hospital wastewaters, the WPS Pilot Plant was intended to serve as a test bed for the general purpose of water treatment. Therefore, a number of flexibilities and additional features such as those shown in Table 10 were incorporated into the WPS.

Design Concept of a Prototype WPS

As part of the present program, the design concept of a prototype WPS was developed. Figure 24 shows the mockup unit of the prototype WPS which consists of the WTU and the WPU. The O_3/UV unit process has been repackaged and integrated into the WTU. The WTU shows the repackaged UF membranes and an inflatable EP tank which is designed to be expandable for transportation. The packaging concept of the prototype WPU is basically the same as for the pilot plant.

DATA ACQUISITION SYSTEM DEVELOPMENT

As part of the WPS pilot plant development, a DAMCS was developed. The DAMCS consists of the following major items:

1. A DAS with data acquisition, retrieval and reduction system in the foreground and program development capability in the background.

2. Automatic Instrumentation for the WPS as a satellite controller of the DAMCS (expandable to 16 satellites).

3. Four remote terminals with alphanumeric CRT/keyboard terminals and/or graphic CRT/keyboard terminals with hard copy unit.

Figure 25 shows the DAMCS hardware and its locations. The DAS and the Automatic Instrumentation Unit are located in the same building which houses the WPS pilot plant. The remote terminals are located approximately within a mile from the DAS mainframe.

Figure 26 is a photograph of the DAS while Figure 27 is a block diagram of the DAS. The DAS consists of two computers--one performs the data acquisition and retrieval control functions in the foreground and the other provides the user with a disk operating system in the background. The foreground computer is dedicated to pilot plant data acquisition, storing and retrieving, while the background computer is designed to generate reports of the pilot plant data. The background computer is also a general purpose computer system which can be used to develop user programs using both assembly language and/or Fortran programming language.

The foreground computer is a minicomputer with 32K words core memory (16-bit per word). The background computer is a minicomputer with 32K words core memory. The foreground minicomputer has all the features of the background plus extended instructions set, higher processing power and additional error detection features. The foreground/background computers share the following

TABLE 9 WATER PROCESSING SYSTEM DESIGN CHARACTERISTICS

Water Treatment Unit	
Overall Dimensions, ft	12 x 8.75 x 6.75
Equalization Tank Wet Volume, gal	1,300
Ultrafiltration Membrane Assembly	
Number of Modules in the Assembly	9 (in parallel)
Number of Membranes per Module	8 (in series)
Total Membrane Surface Area, ft^2	158
Feed Water to UF Membranes	
Flow Rate per Module, gpm	30
Pressure, psia	65
Temperature, F	85 to 125
Water Purification Unit	
Overall Dimensions, ft	9.75 x 5 x 6.75
Reverse Osmosis Membrane Assembly	
Membrane Type	Hollow fiber
Number of Membranes (B-10)	4
Configuration	2:1:1 staged
Total Membrane Surface Area, ft^2	Approx. 7000
Feed Water to RO Membranes	
Flow Rate, gpm	6.6
Pressure, psia	865
Temperature, F	83 to 95
Depth Filter Bed (Diameter x Height), ft	1 x 3
Carbon Adsorption Bed (Diameter x Height), ft	1 x 2.5
Granular Activated Carbon (2 ft^3)	Filtrasorb 200
Ion Exchange Bed (Diameter x Height), ft	3 x 2.83
Resin (21 ft^3)	Amberlite 200
Free Residual Chlorine Level,[a] mg/l	5
UV/Ozone Oxidation Unit	
Overall Dimensions, ft	10 x 8.5 x 6.75
Precontactor Wet Volume, gal	110
Ozone Contactor	
Dimensions, in	40 x 61 x 79
Number of Modules[b]	3
Number of Stages per Module	2
Number of 65 W UV Lamps per Module	20
Total Wet Volume, gal	544
Initial pH	9
Temperature, F	86

(a) After 20 minutes of contact time
(b) For the baseline operation only two modules are required. An additional module is provided for the flexible pilot plant testing.

continued-

Table 9 - continued

<u>UV/Ozone Oxidation Unit</u> - continued	
Ozone Generator	
Ozone Production Capacity, lg/day	25
Ozone Concentration in Air, wt %	1
Air Flow Rate, scfm	24
Power Consumption, kW	18
<u>Automatic Instrumentation Unit</u>	
Overall Dimensions, ft	1.75 x 1.75 x 2.38
Power	60 Hz, 115 V, 750 W
Processor	
Word Size, bits per word	16
Memory Size, words	16,384
Number of Inputs	192
Number of Outputs	85
Message Display Panel Capacity, characters	1,920 (80 x 24)
Number of Manual Overrides	39

TABLE 10 PILOT PLANT FLEXIBILITIES OF THE WPS

- Any Unit Processes can be bypassed
- UF Concentrate Bleed Flow to the UF Feed Tank or the EP Tank
- Interchangeable, Replaceable UF and RO Membranes
- Variable Configuration (series or parallel) of UF and RO Membrane Assemblies
- Recycle-and-Bleed or Once-Through Operation of the RO System
- Variable Number of Ozone Contactor Stages (modular design)
- Variable UV Light Intensity
- Variable Inlet Water Location in the O_3/UV Unit (Precontactor and/or stages 1, 2)
- Replaceable, Maintainable Spargers and UV Lamps
- pH Adjustment in any Stage of Ozone Contactors
- Temperature Adjustment Before or After the Precontactor
- Variable Air/Ozone Flow Rates through Contactors
- Ultrasound in the First Stage of the Ozone Contactor
- Semiautomatic Instrumentation
- Manual Override Capability for Major Components

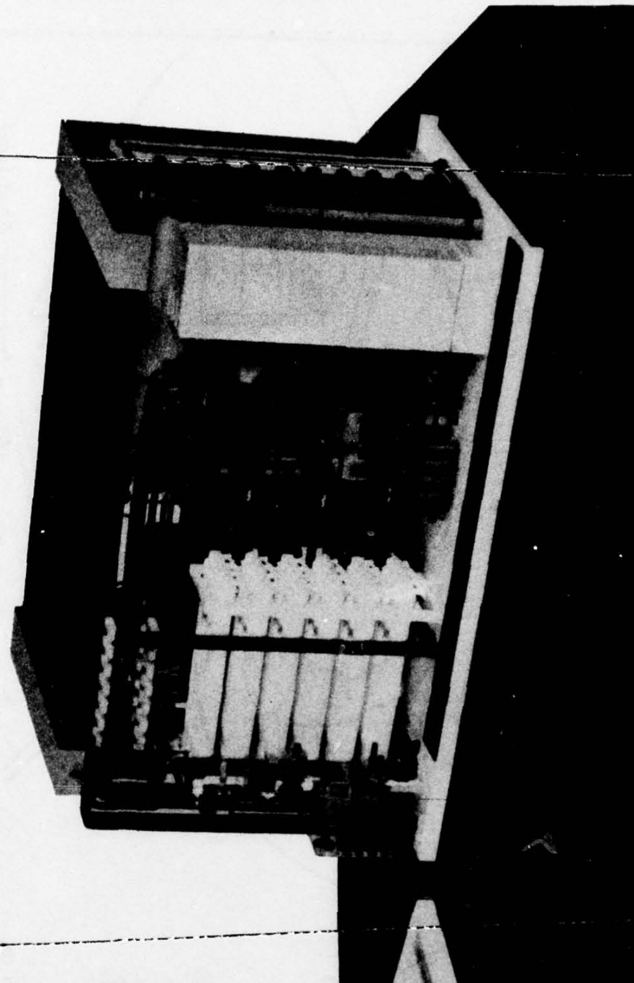


FIGURE 24 PROTOTYPE WPS MOCKUP

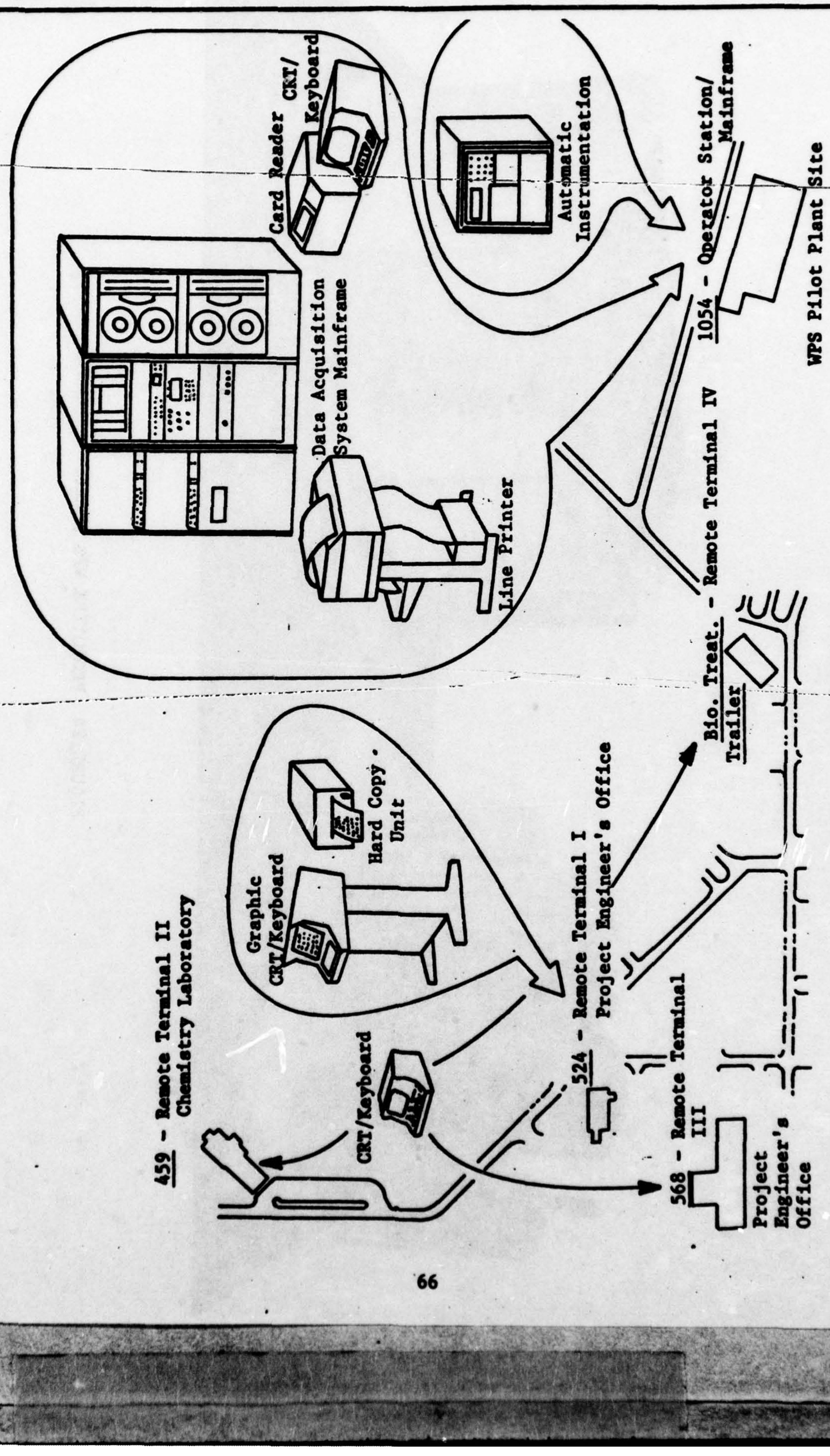


FIGURE 25 DATA ACQUISITION, MONITOR AND CONTROL SYSTEM LAYOUT

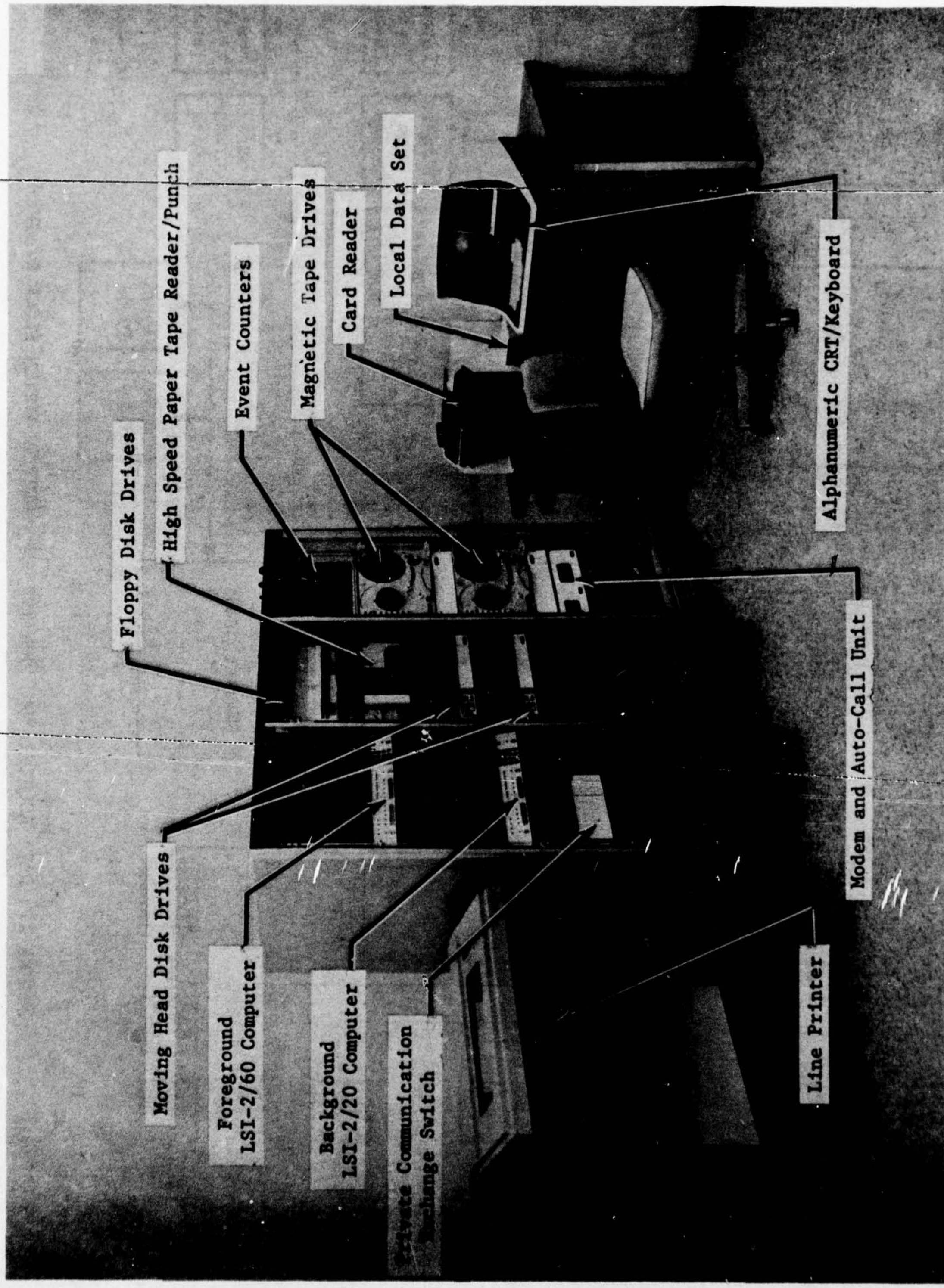


FIGURE 26 DATA ACQUISITION SYSTEM

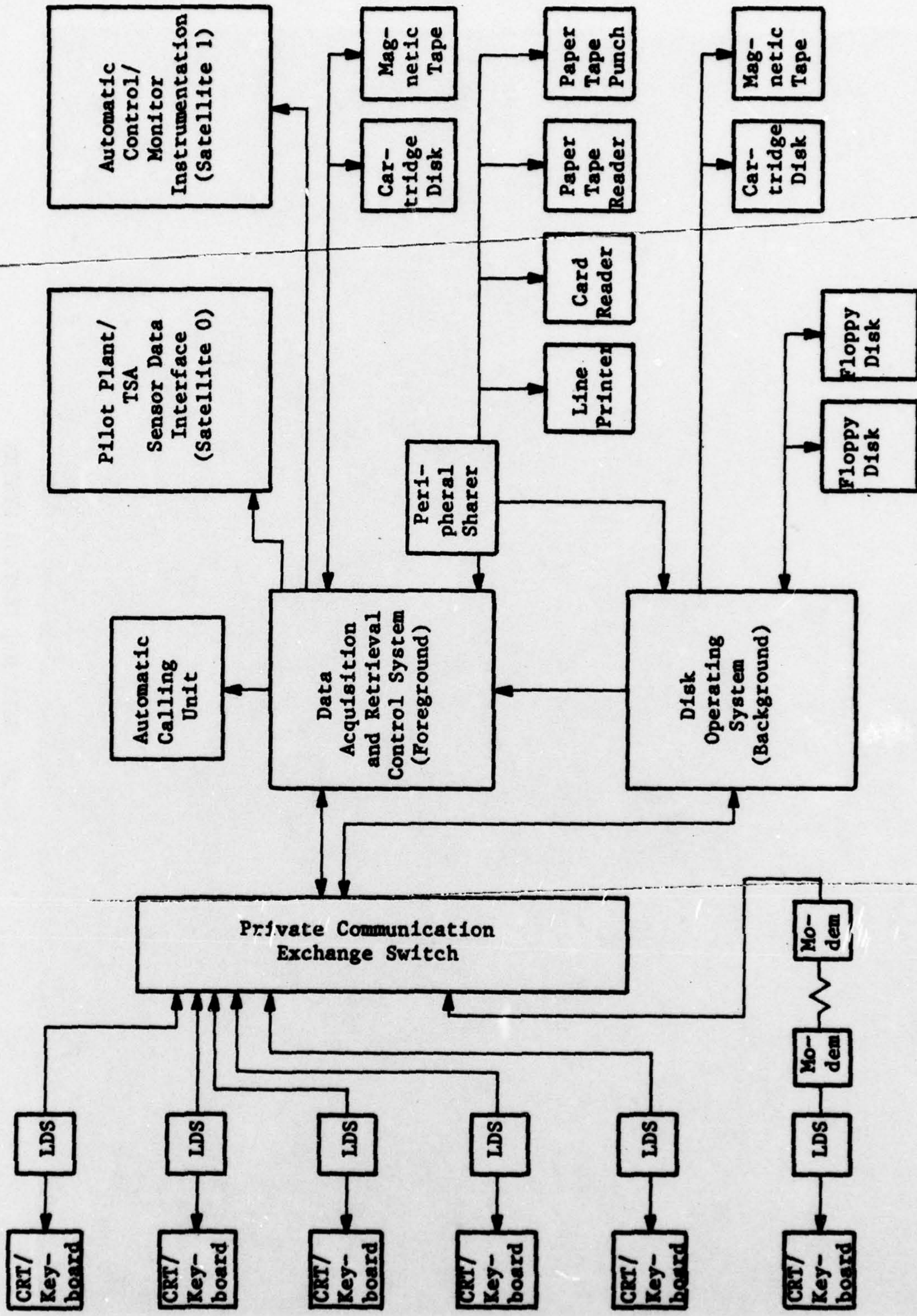


FIGURE 27 DATA ACQUISITION, MONITOR AND CONTROL SYSTEM BLOCK DIAGRAM

peripheral devices: line printer, card reader, paper tape reader and paper tape punch. The connection between these peripheral devices and the computer is selected by the operator using a toggle switch. In addition to the shared peripheral devices mentioned above, the DAS computers can communicate with users at remote terminals through a CRT/keyboard terminal, a local data set or modem and a private communication exchange switch. The communication link to either computer can be selected by an operator using the thumb-wheel switch on the local data set. Each of the DAS computers has a moving head cartridge disk pack capable of a five megabyte storage and a magnetic tape transport capable of a 23 megabyte storage on an 8-1/2 inch reel of tape at a density of 1,600 bits per inch. The background computer also has a dual floppy disk subsystem. Each of the floppy disk drives has a storage capacity of 1/4 megabytes. The foreground computer has an automatic calling unit which is designed to originate a telephone call to the project engineer when an alarm condition exists in the pilot plant testing. The foreground computer was designed to handle up to 16 satellite controllers for data collection. Presently, only two satellites (Satellite 0 and Satellite 1) were implemented. Satellite 0 was designed to correct the pilot plant sensor data. No control or monitor functions were incorporated into Satellite 0. Satellite 1 is the Automatic Instrumentation Unit of the WPS pilot plant. It controls and monitors the pilot plant and transmits sensor data to the DAS foreground computer. The sensor data collected by the DAS foreground computer are stored on the disk pack. The magnetic tape transport was designed to be the backup storage for the pilot plant sensor data.

The DAS was also designed to have the capability of operating the Automatic Instrumentation Unit from a remote terminal. A user may enter an operator command via a CRT/keyboard terminal. The command will be transmitted to the Automatic Instrumentation Unit via the local data set and/or modem, the private communication exchange switch and the DAS foreground computer. The results of this remote operation are the same as if the operator were using the Automatic Instrumentation Unit front panel. Such operator control actions are automatically logged on the foreground computer disk pack for future reference.

The DAS provides the user with the following features and benefits:

- Automatic data acquisition of pilot plant sensors at individually selectable query rates (5, 15, 30 and 60 minutes).
- Automatic conversion of sensor signals to engineering units.
- Storage of pilot plant sensor data on disk pack for at least 24 hours.
- Backup magnetic tapes for long-term sensor data storage.
- Sensor data report showing minimum, average, maximum data points and the number of excursions beyond the caution, warning and alarm setpoints.
- Remote operation of the DAS and the pilot plant using the communication links.

- Manipulation and reconstruction of the control and monitor characteristics of the Automatic Instrumentation Unit from a remote terminal.
- User program development on the background computer.

CONCLUSIONS

The following conclusions were drawn from this development program:

1. The integrated, multifunctional WPS is a viable solution to meet the needs for the multipurpose water treatments in the field Army medical facilities.

2. The WPS pilot plant was designed to be capable of producing potentially nonpotable reuse water from nonsanitary hospital wastewaters and producing potentially drinkable water from natural waters while treating the hospital wastewaters for safe discharge to the environment. This is accomplished by the use of various combinations of the six unit processes EP, UF, RO, DF/IE, O_3/UV and HC.

3. A DAS and a number of flexibilities incorporated into the WPS enable the pilot plant to serve as a test bed for treatment of other wastewaters generated in Army installations.

4. A prototype WPS could have been housed in two standard ward containers for transportation as demonstrated by a prototype mockup and the compact design of the WPS pilot plant.

5. The O_3/UV oxidation is an effective process for the tertiary treatment of the hospital wastewaters. The overall reaction in the range of interest is first-order with respect to the TOC concentration and also has 1.5th-order dependence on the ozone partial pressure and the gas superficial velocity.

6. Operation and maintenance of the WPS has been greatly simplified by the use of minicomputer-based automatic instrumentation. The complicated process and parameter controls for the multifunctional WPS are fully automated so that a soldier with low skill levels and limited training can operate the systems.

7. The DAS provides a project engineer with the capability of operating and monitoring 15 Water Processing Systems installed in remote locations. The number of systems to be supervised can be easily expanded.

RECOMMENDATIONS

The following recommendations are direct results of this program:

1. Integrated testing of the WPS with simulated hospital wastewaters should be performed to evaluate and characterize the performance of the WPS.

2. The functional requirements and missions of the WPS should be reassessed, taking into account the possible revision of the MUST concept. It is probable that the WPS could treat other wastewaters generated at Army installations as well as field hospital wastewaters.

3. The WPS pilot plant should be used as a flexible test bed to evaluate the treatability of various kinds of wastewaters generated in fixed federal facilities. The treatability study should identify a unique combination of unit processes best suited for a certain specific wastewater.

4. The pilot plant should be used to obtain all the design data necessary for an optimum design of a prototype system, once the best combination of treatment processes is determined for a specific wastewater.

5. The prototype treatment system design for a specific wastewater including the hospital wastewaters should be based on the best combination of unit processes (as a subdivided unit of the WPS) to result in a more compact design with less volume, weight and power consumption. It is recommended that all the sensors, controls and other auxiliary components implemented in the WPS for scientific data development and pilot plant flexibilities should be eliminated in the prototype system design.

REFERENCES

1. Smith, R. S., "Water Quality Engineering Special Study, Evaluation of the Water Processing Element, Medical Unit, Self-Contained, Transportable (MUST)," USAEHA Control No. 99-003-71, 1971.

2. Bryce, C. A., Heist, J. A., Leon, R., Daley, R. J. and Holyer Black, R. D., "MUST Waste Water Treatment System," Final Report, Contract DADA17-71-C-1090, SPS-5062-R5, AiResearch Manufacturing Company of Arizona, Garrett Corp., Phoenix, AZ, July, 1973.

3. Gollan, A. Z., McNulty, K. J., Goldsmith, R. L., Kleper, M. H. and Grant, D. C., "Evaluation of Membrane Separation Processes, Carbon Adsorption, and Ozonation for Treatment of MUST Hospital Wastes," Final Report, Contract DAMD17-74-C-4066, ADAO 30057, Walden Research Division of Abcor, Inc., Wilmington, MA, August, 1976.

4. See, G. G., Yang, P. Y. and Kacholia, K. K., "Research and Development of An Ozone Contactor System," Final Report, Contract DAMD17-76-C-6041, ER-300-4, Life Systems, Inc., Cleveland, OH, June, 1976.

5. See, G. G., Kacholia, K. K. and Wynveen, R. A., "Control and Monitor Instrumentation for MUST Water Processing Element," Final Report, Contract DAMD17-73-C-3163, ER-246-6, Life Systems, Inc., Cleveland, OH, June, 1975.

6. Chian, E. S. K. and Fang, H. H. P., "Evaluation of New Reverse Osmosis Membranes for the Separation of Toxic Compounds from Wastewater," Second Annual Summary Report, Contract DADA17-73-C-3025, UILU-ENG-74-2028, University of Illinois, Urbana, IL, October, 1974.

7. Chian, E. S. K. and Kuo, P. P. K., "Fundamental Study on the Post Treatment of RO Permeates from Army Wastewaters," Second Annual Summary Report, Contract DAMD17-75-C-5006, UILU-ENG-76-2019, University of Illinois, Urbana, IL, October, 1976.

8. Sierka, R. A., "Mass Transfer and Reaction Rate Studies of Ozonated MUST Wastewaters in the Presence of Sound Waves," Final Report, Contract DAMD17-76-C-6057, UA-ENGR-1436, University of Arizona, Tucson, AZ, August, 1976.

9. Sierka, R. A., "Activated Carbon Treatment and Ozonation of MUST Hospital Composite and Individual Component Wastewaters and MUST Laundry Composite Wastewaters," Technical Report 7502, U.S. Army Medical Bioengineering Research and Development Laboratory, Fort Detrick, Frederick, MD, March, 1975.

10. McCarthy, J. J., Cowen, W. F., Chian, E. S. K. and Peterman, B. W., "Evaluation of an Air Stripping-Ozone Contactor System," Technical Report 7707, U.S. Army Medical Bioengineering Research and Development Laboratory, Fort Detrick, Frederick, MD, June, 1977.

11. Lee, M. K., Yang, P. Y. and Wynveen, R. A., "Water Treatment Unit Development for Field Army Medical Facilities," Technical Report, Contract DAMD17-76-C-6063, ER-314-7-2, Life Systems, Inc., Cleveland, OH, March, 1978.

12. Lee, M. K., Yang, P. Y. and Wynveen, R. A., "Water Purification Unit Development for Field Army Medical Facilities," Technical Report, Contract DAMD17-76C-6063, ER-314-7-3, Life Systems, Inc., Cleveland, OH, April, 1978.

13. Yang, P. Y., Yeh, J. Y., Powell, J. D. and Wynveen, R. A., "Advanced Instrumentation Development for a Water Processing Pilot Plant for Field Army Medical Facilities," Technical Report, Contract DAMD17-76C-6063, ER314-7-4, Life Systems, Inc., Cleveland, OH, May, 1978.

14. Lee, M. K. and Yang, P. Y., "UV/Ozone Oxidation Technology Development for Water Treatment for Field Army Medical Facilities," Technical Report, Contract DAMD17-76-C-6063, ER-314-7-5, Life Systems, Inc., Cleveland, OH, July, 1978.

15. Yang, P. Y., Yeh, J. Y. and Wynveen, R. A., "Data Acquisition, Monitor and Control System Development for Field Army Medical Facilities," Technical Report, Contract DAMD17-76-C-6063, ER-314-7-6, Life Systems, Inc., Cleveland, OH, August, 1978.

16. Lee, M. K., "A UV-Ozone Oxidation Kinetic Study and Reactor Design for the Water Processing Element," presented at the French Lick Ozone Conference, Sponsored by U.S. Army Medical Research and Development Command, French Lick, IN, ER-349, Life Systems, Inc., Cleveland, OH, August 10, 1977.

17. McCarthy, J. J., "Ozonation of Synthetic Hospital Composite RO and UF Permeate Using the Westgate Unit Reactor Module," Memorandum to W. P. Lambert, May 17, 1977.

18. See, G. G. and Yang, P. Y., "Water Processing Element Operation Manual," Contract DAMD17-76C-6063, ER-314-38, Life Systems, Inc., Cleveland, OH, September, 1977.

19. See, G. G., "WPE/DAMCS Pilot Plant Maintenance Manual for the Water Purification Unit," Contract DAMD17-76-C-6063, ER-314-5-1, Life Systems, Inc., Cleveland, OH, April, 1977.

20. See, G. G., "WPE/DAMCS Pilot Plant Maintenance Manual for the Water Treatment Unit," Contract DAMD17-76C-6063, ER-314-5-2, Life Systems, Inc., Cleveland, OH, 1977.

21. Brown, K., "Ozone Oxidation Unit Process Maintenance Manual," Contract DAMD17-76-C-6063, ER-314-39, Life Systems, Inc., Cleveland, OH, October, 1977.

22. Lee, M. K., See, G. G. and Wynveen, R. A., "Reaction Kinetics of UV/Ozone with Organic Compounds in Hospital Wastewater," Presented at the Symposium on Advanced Ozone Technology, Sponsored by International Ozone Institute, Inc., Toronto, Canada, ER-345, Life Systems, Inc., Cleveland, OH, November 16 - 18, 1977.

23. U.S. Army Medical Research and Development Command RFQ No. DAMD17-76-Q-6561, "MUST Water Processing Element Pilot Plant Development," May 3, 1976.

APPENDIX 1 MUST CONCEPT

In June 1962, the Surgeon General initiated action for the development of a mission-oriented medical treatment system known as the Medical Unit, Self-Contained, Transportable (MUST). This system was to be designed for rapid establishment and disestablishment and to be directly responsive to any tactical, environmental or geographical situation.

Requirements for the MUST medical complex specify that all waste materials generated therein be rendered inert or nontoxic prior to disposal. The MUST medical complex organization is defined in Figure A1-1. It shows the relationship of the Water and Waste Managment Subsystem to the other medical complex structural elements. The principal functional elements of the Water and Waste Management Subsystem are also illustrated.

Three Basic Hospital Configurations

One of the operational characteristics of the MUST medical complex is the "building block" concept. Various numbers (blocks) of the basic structural elements may be combined into any desired medical configuration but generally will be combined to form three basic types of field medical units:

1. Mobile Army Surgical Hospital (60-bed medical units - to be cancelled)
2. Combat Support Hospital (200-bed medical units)
3. Evacuation Hospital (400-bed medical units)

Many medical complex configurations exist based on the arrangement of the structural elements.

Structural Elements

The MUST medical complexes consist of various groupings of three basic structural elements: Air Inflatable, Expandable and Utility.

Air Inflatable. The Air Inflatable Element provides for preoperative preparation, postoperative recovery, hospital ward outpatient treatment, patient decontamination/receiving, supply food service and laundry.

Expandable. The Expandable Element provides for operating rooms, sterile preparation area, pharmacy, clinical laboratory, X-ray, oral (dental) surgery and food service.

Utility. The Utility Element provides electrical power, water pumping and heating, compressed air and suction, environmental control and positive air pressure circulation, and filtration for protection against toxic contaminants from the outside environment.

continued-

Appendix 1 - continued

Water and Waste Management Subsystem

The Water and Waste Management Subsystem is contained in service ward containers (see Figure A1-2) and has three principal subelements: Utility Room, Mobile Incinerator and Water Processing System. A 400-bed Evacuation Hospital, for example, would require five Utility Room Elements, two Mobile Incinerator Elements and ten WPSs. The Water and Waste Management Subsystem is at an equal, but separate, configurational level to the three basic MUST medical complex structural elements.

Utility Room. The Utility Room Element consists of four "Kits" that provide sanitary facilities for 60 patients. This includes lavatory facilities for washing, shaving and normal personal oral hygiene, showers, toilets and sanitizers.

Wastewater from the Shower and Lavatory Kits are discharged to the WPEs. However, wastewater from the Toilet and Sanitizer Kits is disposed of in a portable waste incinerator located within the Toilet Kit.

Mobile Incinerator. The mobile incinerator disposes of waste products generated within the medical complex. Typical wastes include plastic products, garbage and general food wastes, paper, wood, packing material, and liquid waste generated throughout the medical complex (e.g., contaminated medical solid wastes, concentrated wastewater from the WPE blowdown waste, etc.).

Water Processing. The WPS consists of a Water Treatment Unit (WTU) and a Water Purification Unit (WPU). The WPS is designed to treat all wastewaters, with the exception of human waste, generated within the functional areas of the hospital. Each unit is housed in a specially modified MUST ward container.

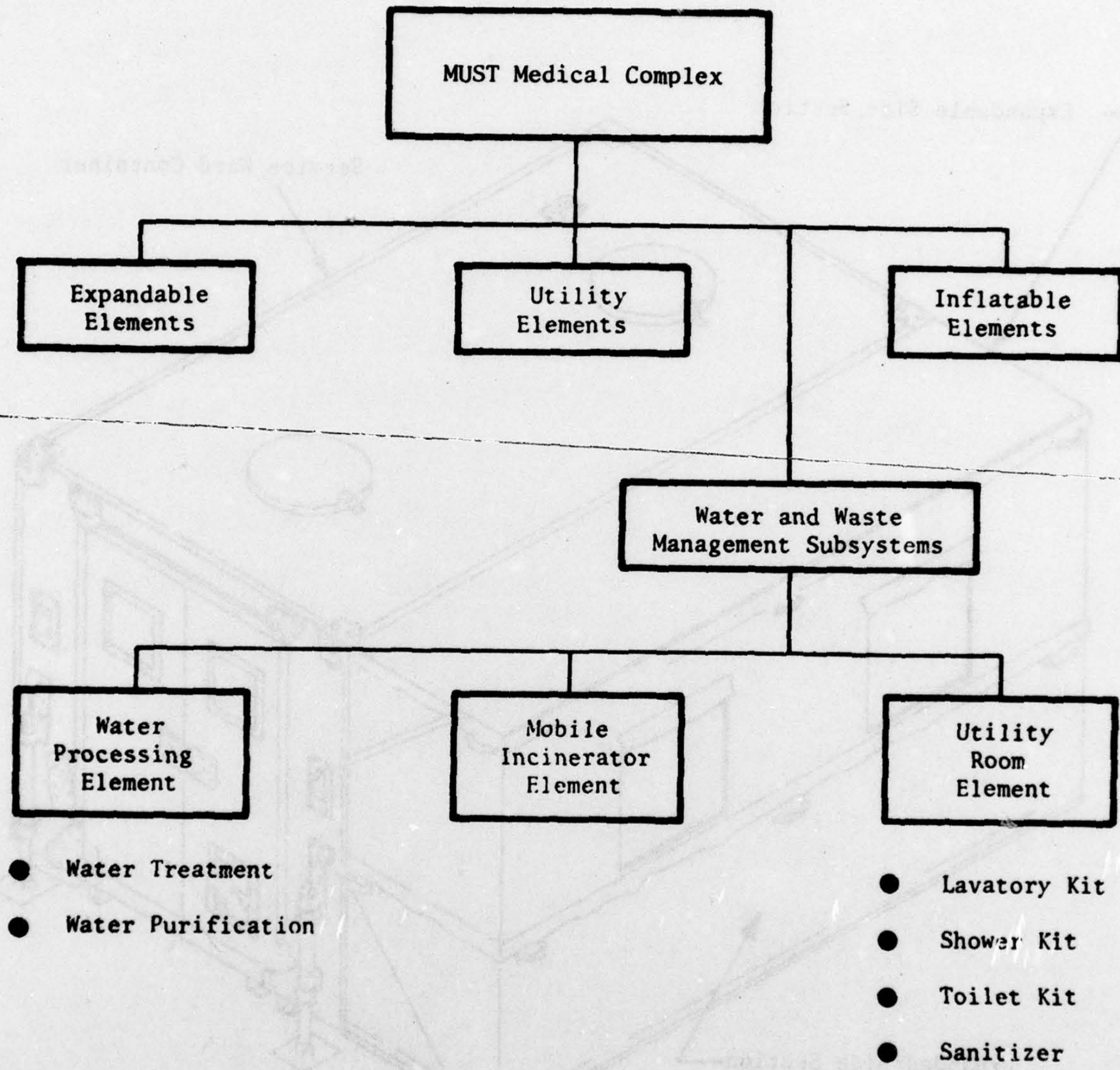


FIGURE A1-1 MUST MEDICAL COMPLEX ORGANIZATION

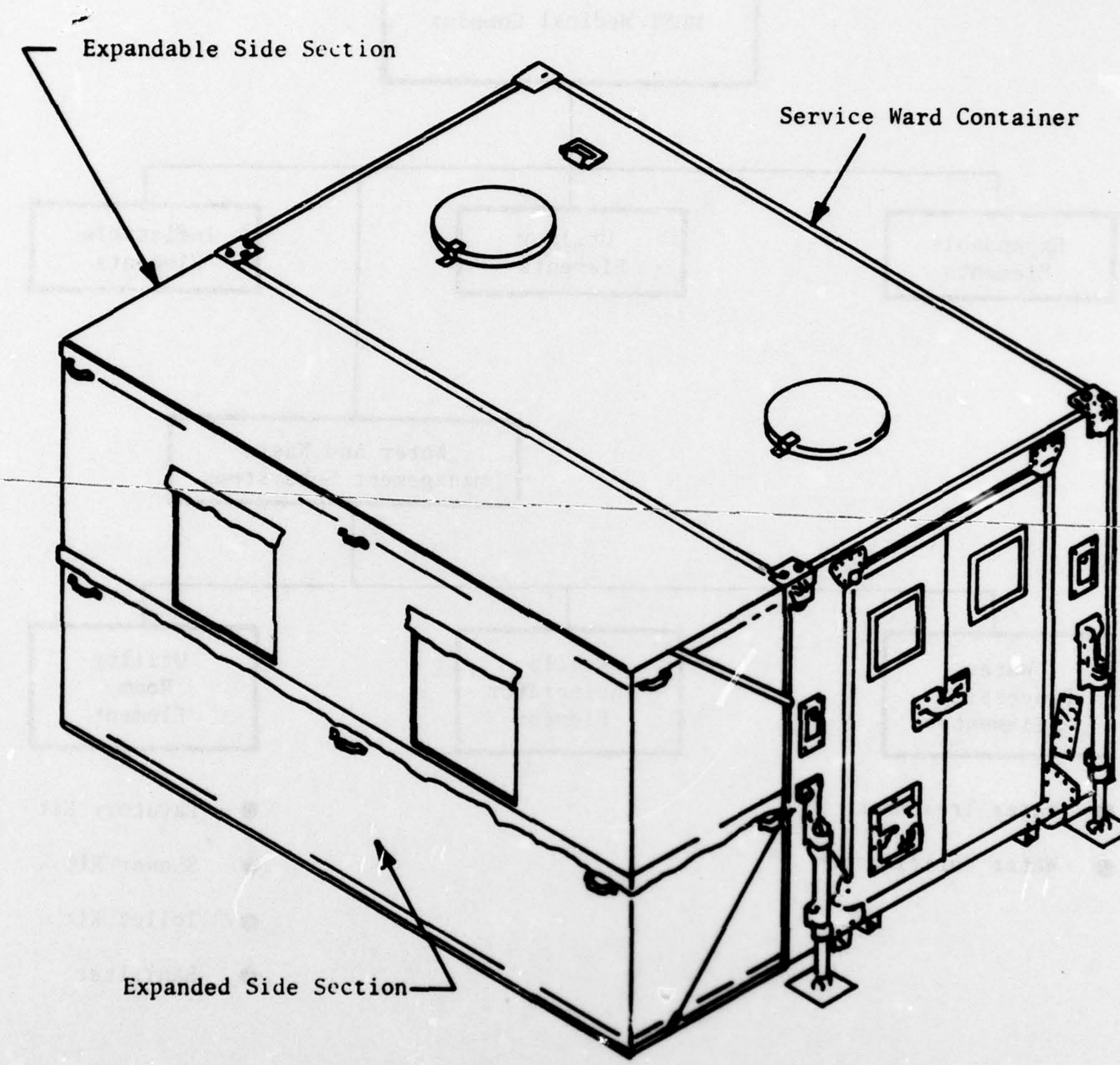


FIGURE A1-2 SERVICE WARD CONTAINER (EXPANDED MODE)

APPENDIX 2

FLOW SCHEMATIC OF WATER PROCESSING SYSTEM PILOT PLANT

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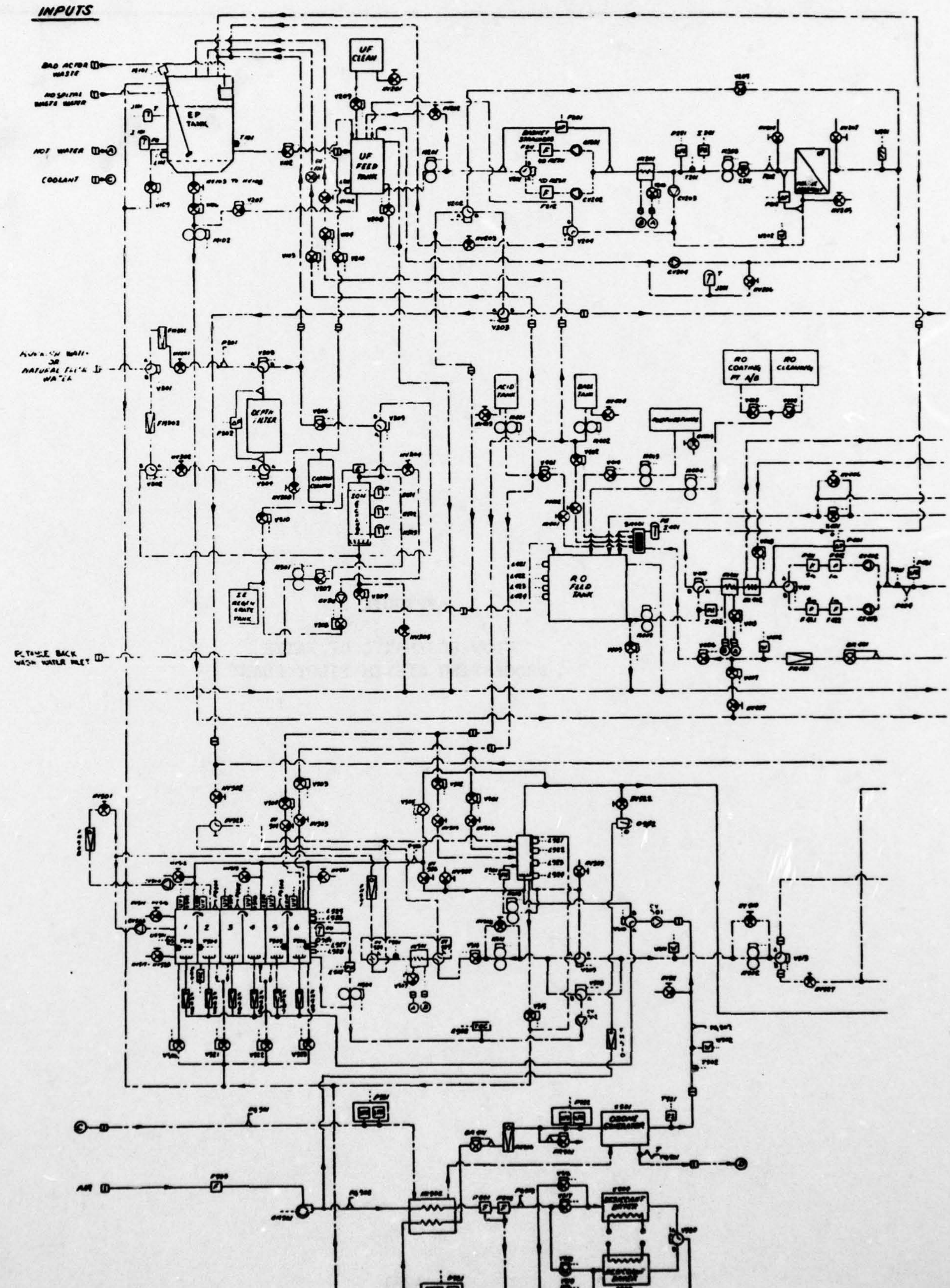
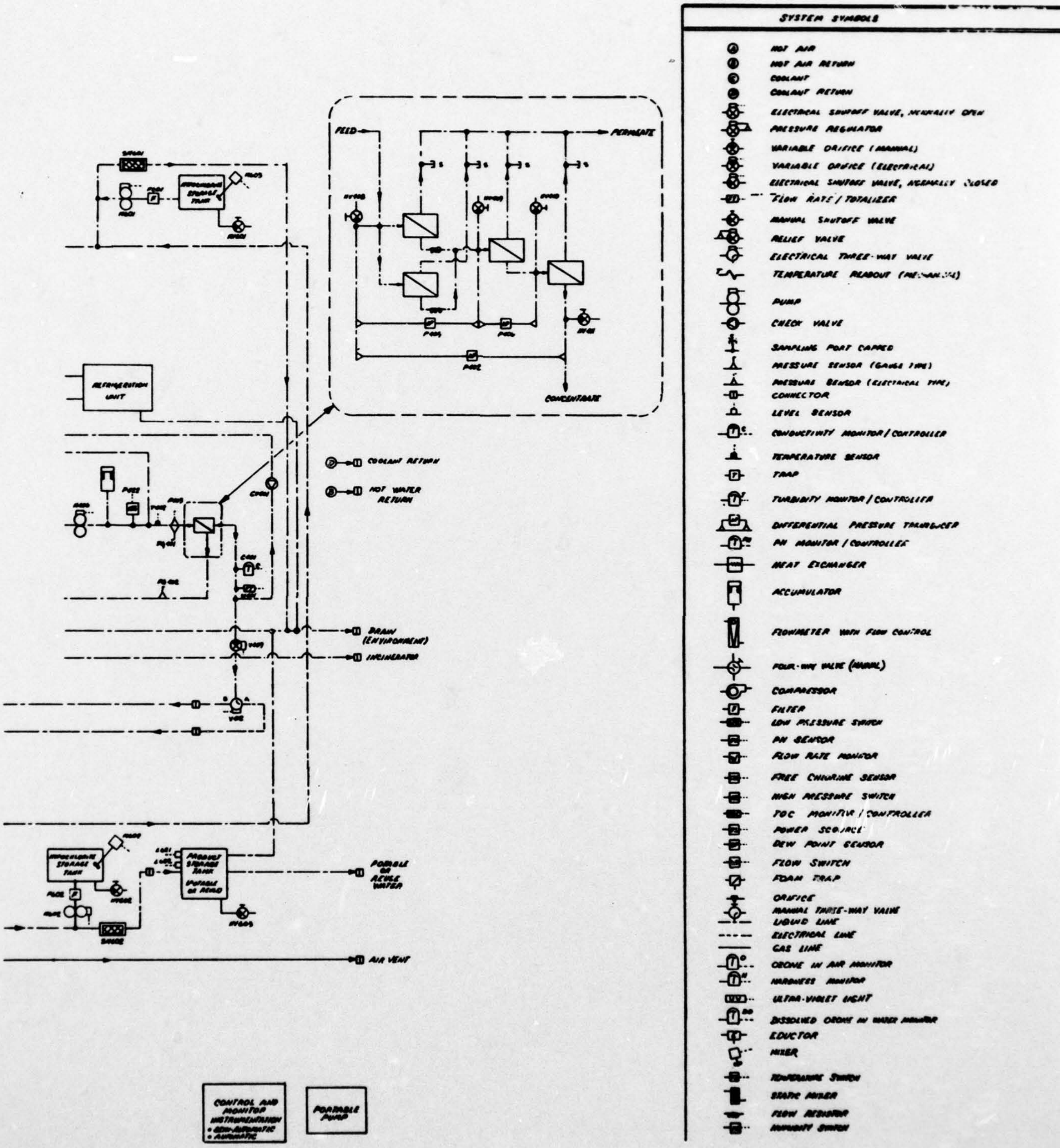


OUTPUTS



NOTE:
1) SAMPLE VALVES SHOWN AT THE TOP AND BOTTOM OF STAGE I OF THE OZONE CONTACTOR ARE ON ALL STAGES BUT NOT SHOWN FOR SIMPLICITY.

APPENDIX 3

SYSTEM INTERFACES

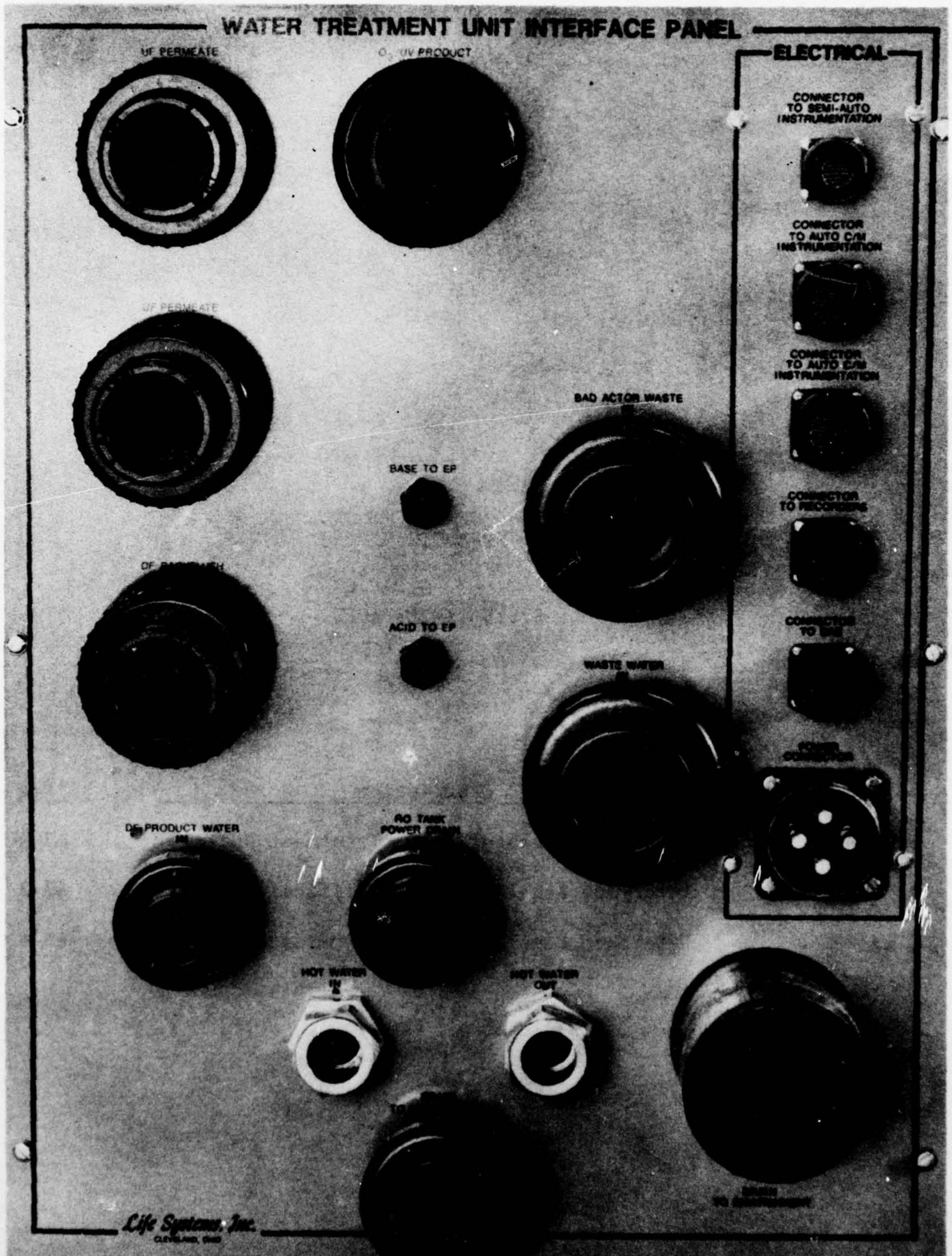


FIGURE A3-1 INTERFACE PANEL OF WATER TREATMENT UNIT

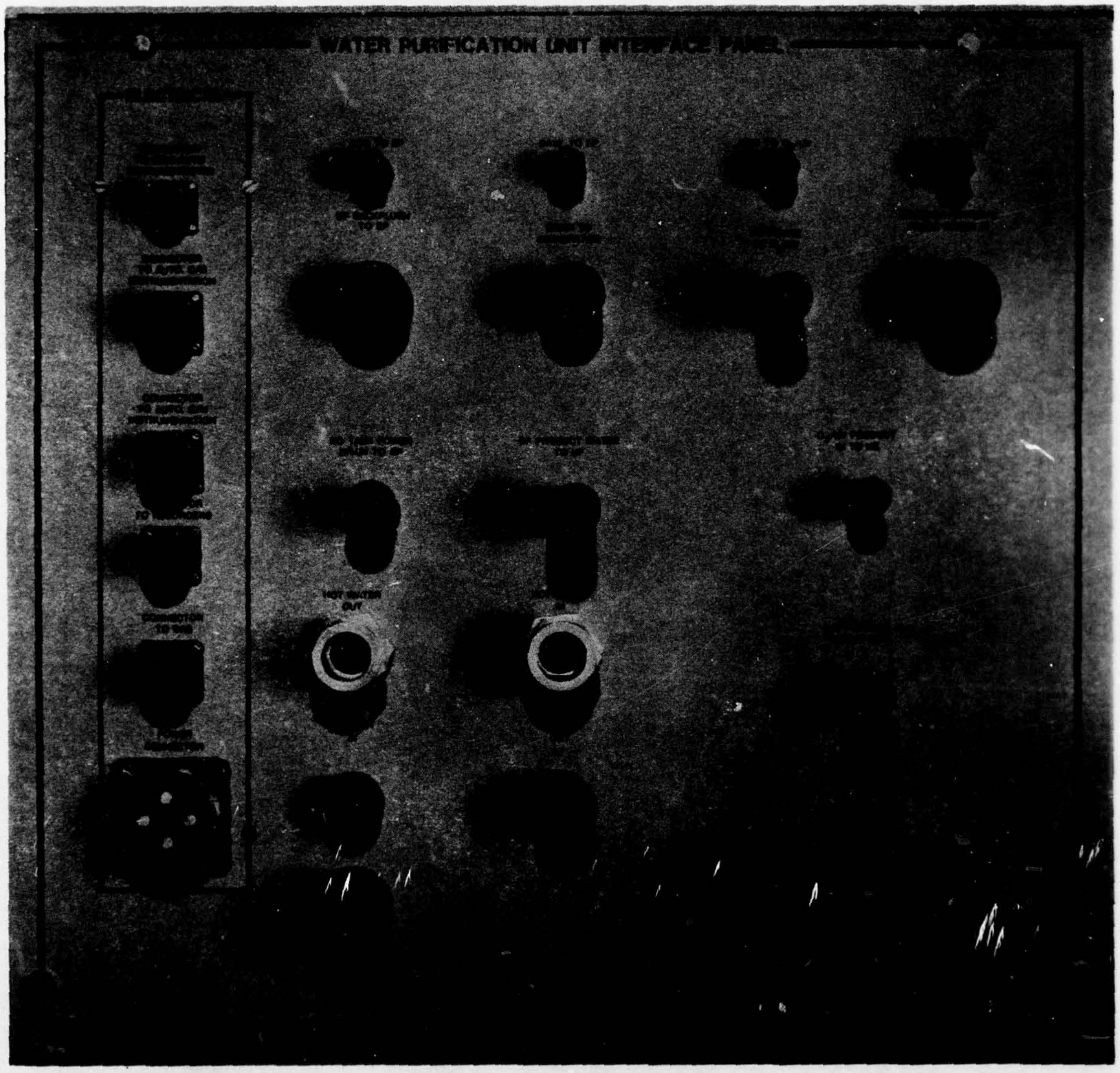


FIGURE A3-2 INTERFACE PANEL OF WATER PURIFICATION UNIT

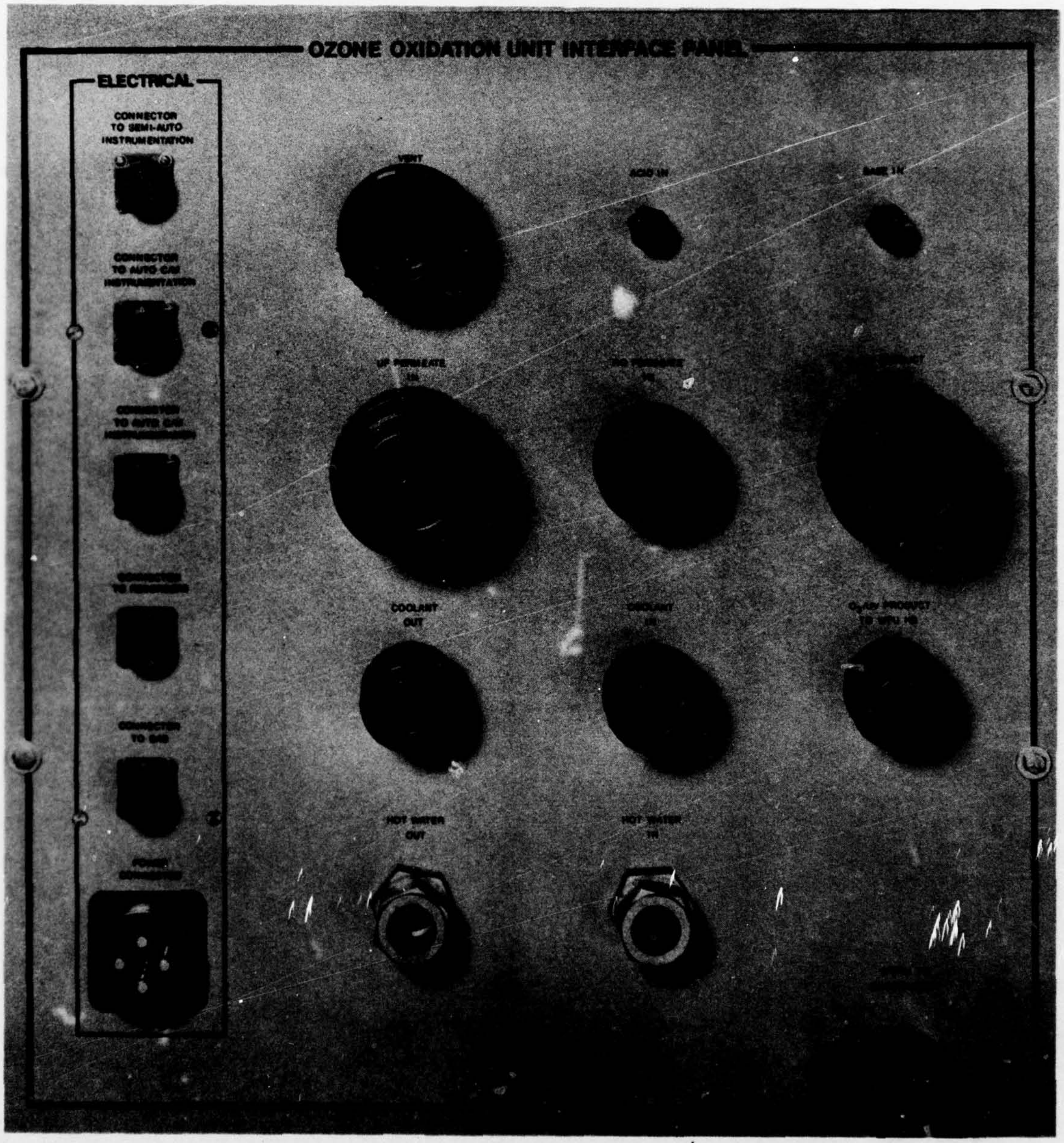


FIGURE A3-3 INTERFACE PANEL OF UV/OZONE OXIDATION UNIT

APPENDIX 4 COMPOSITIONS OF SIMULATED HOSPITAL WASTEWATERS

Wastewater	Constituent	Concentration	
Shower	Hair Oil	150	mg/l
	Shower/Lavatory Cleaner	100	mg/l
	Sodium Chloride	83	mg/l
	Soap	69	mg/l
	Hair Gel	37	mg/l
	Toothpaste	37	mg/l
	Talc	20	mg/l
	Soil (Kaolinite)	19	mg/l
	Hair	10	mg/l
	Hair Shampoo	5	mg/l
	Phisohex Soap	3	mg/l
	Mouthwash	2	mg/l
	DEET (Insect Repellent)	1	mg/l
	Deodorant	1	mg/l
	Hair Coloring	1	mg/l
	Hair Dye	1	mg/l
	Urea	1	mg/l
Operating Room	Haema-Sol	750	mg/l
	Betadine	722	mg/l
	Sodium Chloride	461	mg/l
	Hair	414	mg/l
	Wescodyne	136	mg/l
	Blood	360	µl/l
Kitchen	Detergent Type I (FSN7930-634-3935)	1890	mg/l
	Sparkleen	1510	mg/l
	Suspended Solids (Dog Food)	1200	mg/l
	Scouring Powder (FSN 7930-205-0442)	189	mg/l
	Vegetable Oil	150	mg/l
	Grease (Lard)	100	mg/l
	Hand Soap		
Laboratory[(a)]	Sparkleen	302	mg/l
	1 1/2% Thioglycolate	3.77	mg/l
	0.85% Sodium Chloride	3.62	mg/l
	Zinc Sulfate	2.49	mg/l
	Urine	2560	µl/l
	Blood	1060	µl/l
	Dichromare Cleaning Solution	755	µl/l

(a) Formula will undergo modification as part of USAMBRDL effort to reduce load on WPS through variations in MUST Medical Complex procedures, e.g., elimination of urine by pouring into a vat and then into the incinerator and elimination of methyl alcohol by (1) using prepared laboratory stain sets or (2) substitution with another alcohol (ethanol, propanol or isopropanol).

continued-

Appendix 4 - Continued

Wastewater	Constituent	Concentration	
Laboratory - continued	0.1N Sodium Hydroxide	272	µl/l
	1 1/2% Blood Agar	249	µl/l
	1 1/2% Chocolate Agar	249	µl/l
	1 1/2% EMB Agar	249	µl/l
	Methyl Alcohol	242	µl/l
	5% Phenol Solution	189	µl/l
	1 1/2% Agar	139	µl/l
	Giemsa Stain	90.6	µl/l
	Wright Stain	83.0	µl/l
	Acetone	75.5	µl/l
	O-Toluidine Reagent	41.5	µl/l
	Lysol (undiluted)	37.7	µl/l
	Biuret Reagent	22.6	µl/l
	Lithium Diluent	22.6	µl/l
	Phenol Color Reagent	18.9	µl/l
	Alkali-hypochlorite Reagent	15.1	µl/l
	Crystal Violet Stain	15.1	µl/l
	10% Formaldehyde	15.1	µl/l
	KI-I Solution	15.1	µl/l
	Safranin	15.1	µl/l
	22.2% Sodium Sulfate Solution	15.1	µl/l
	3% Sulfosalicylic Acid	15.1	µl/l
	30% Trichloracetic Acid	11.3	µl/l
	Buffered Substrate	7.55	µl/l
	Bilirubin Standard	7.55	µl/l
	2% Sodium Citrate Solution	7.55	µl/l
	Diazo Reagent	7.55	µl/l
	DNPH Color Developer	7.55	µl/l
	Ether	7.55	µl/l
	Immersion Oil	7.55	µl/l
	Spinal Fluid	7.55	µl/l
X-ray[(a)]	Silver Chloride	215	mg/l
	Phisohex Soap	214	mg/l
	Kodak X-Omat Developer	28.3	ml/l
	Kodak X-Omat Fixer	28.3	ml/l
Laundry Type I	Detergent Type I (FSN 7930-634-3935)	650	mg/l
	Alkalinity	500	mg/l
	Oil and Grease (Vegetable Oil)	200	mg/l
	Kaolinite Clay	150	mg/l

(a) X-ray waste may eventually be eliminated when the dry X-ray becomes standard military procedure.

continued-

Appendix 4 - Continued

Wastewater	Constituent	Concentration	
Laundry Type I	Sour (Downey Fabric Softener)	116	mg/l
	Urea	20	mg/l
	DEET	19	mg/l
	Blood	874	µl/l
Laundry Type II	Detergent Type II (FSN 7930-664-0337)	518	mg/l
	Alkalinity	500	mg/l
	Sour	116	mg/l
	Kaolinite Clay	100	mg/l
	Oil and Grease (Vegetable Oil)	100	mg/l

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